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Effect of shrinkage on the design and manufacture of plastic parts in injection molding using CAD/CAM techniques

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EFFECT OF SHRINKAGE ON THE DESIGN AND MANUFACTURE OF PLASTIC PARTS IN INJECTION MOLDING USING CADCAM TECHNIQUES

by

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ABSTRACT

Computer aided design software in injection molding has revolutionized injection molding, in the design and manufacturing processes. Computer Aided Engineering can be applied to injection molding to increase the process efficiency, reduce part costs, and produce accurate parts in less time. The mold designer has many software programs to choose from to produce satisfactory mold designs from part geometries, and a correct selection can produce profitable results. A study of the need for and the scope of computers in injection molding is performed to evaluate the suitability of a CAE package by considering the value added to the parts using these techniques. The interactive nature of the programs is illustrated with examples and also the ability of the programs to perform simulations of the processes are studied and the accuracy and reliability of the programs is considered.

Evaluation of part shrinkage is very important to mold parts of required accuracy. The currently used methods in CAD mold design have one major drawback that mold designers experience. The variation in shrinkage coefficients for different resins cannot be compensated for and one cannot predict whether a specific part can be manufactured without warpage. Most CAD simulations cannot accurately predict the variation in shrinkage rates across all dimensions of a specific part. The factors influencing part shrinkage are studied and the variation of shrinkage with molding conditions is illustrated from previous experiments. A comprehensive plan is suggested to perform experiments to enable prediction of part shrinkage more accurately.

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Chapter 1

INTRODUCTION

1.1 The Manufacture of Plastic Parts - Prior to Mold Filling Analysis

The manufacture of plastic parts by injection molding is an involved process and it is performed in two stages, the design stage and the prototyping stage. Figure 1.1 shows the traditional method of plastic part manufacture in the injection molding process.

The design stage, which involves many empirical relationships, comprises many steps which are time consuming such as mold design and drafting. A product design drawing is made showing the geometry of the part, the material specifications and specifications for functional requirements. On the basis of this drawing the mold is constructed in which the part can be produced. The molding machine facilitates the mold filling and the solidification of the melt into the desired shape. When the part solidifies the mold is opened to remove the finished product. The molded part is only as good as the mold from which it is produced. A good design, implemented with good workmanship, can produce an acceptable part. A poorly working mold necessitates an excessive amount of attention from key personnel and leads to high production costs as well as producing a part of poor quality that may

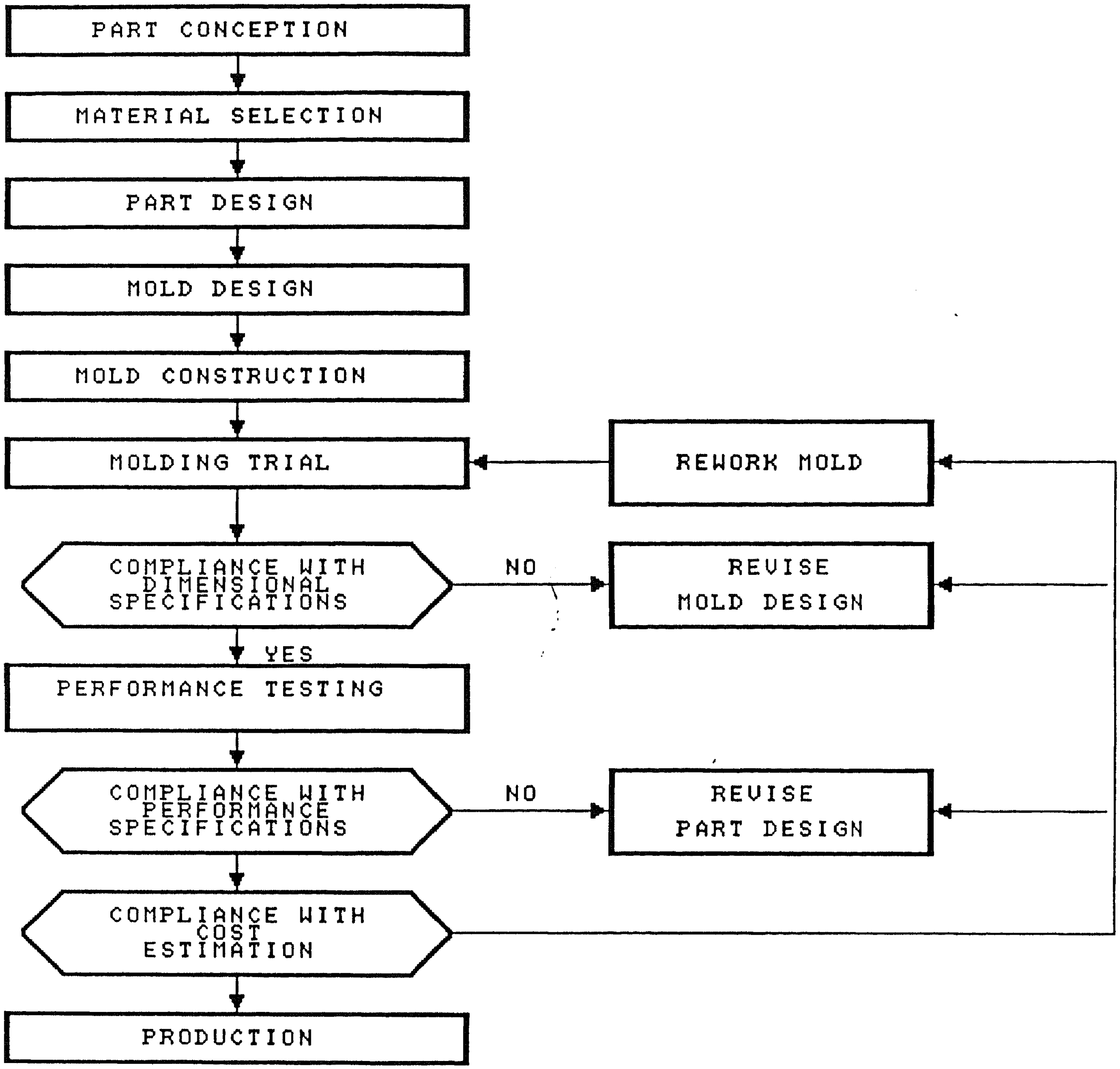

Figure 1.1: Traditional method of manufacturing injection molded parts

fail its functional requirements.

It is undesirable to construct a mold that produces parts that do not meet specifications or that costs more than the quoted price. Hence a preliminary protoype design of the mold is made and it is used to mold the part. The part is then tested for quality and functional requirements. If the part does not meet the requirements then the necessary changes are incorporated into the mold design and mold making. The mold is then retested. This is continued until the desired product is produced. This is called the prototyping stage and it involves several iterations and it would be desirable to reduce the iterations required to produce a viable prototype in order to reduce the time involved and also the costs in making it. The iterations are costly and can cause the prototyping stage to cost more than the design stage. It is usually impossible to get a mold that provides the intended level of quality and cost on the first attempt. It is important to engineer the mold prior to construction.

The plastic parts should be designed for manufacturability by considering the effectiveness of the manufacturing process. The effectiveness of the manufacturing process is directly proportional to the value added to the raw material by the processing. But any processing of the raw material would incur an added cost for the part. The aim of the designer should be to create a well designed part so as to increase the value of the part and also to reduce the cost of manufacturing. While designing a part, it should be noted that functional requirements cannot always be stated clearly and may change. Several iterations may be needed to arrive at a satisfactory design and new solutions may be necessary. Plastics can replace metal products effectively when designed on the basis of functional requirements and not as physical look-alikes.

1.2 Need for Computers in the Design and the Manufacture of Plastic Parts

The plastics industry is a dynamic field and a successful manufacturer needs to have vast experience, in addition to labor and resources. The injection molding process has many uncertain parameters that make the process complicated. To be competitive in injection molding, optimum productivity and short start-up times are desired. Since this process requires labor, economic considerations demand a high efficiency in the process.

The parameters in this process such as the viscoelastic properties of the plastic, irregular mold geometries and steep temperature gradients make the mold design stage complicated. The low temperature of the mold cavity causes a steep temperature gradient at the time of mold filling. This, in turn, causes a frozen skin to be formed during the flow stage which decreases the cross section of the flow channel and thus increases the pressure drop. This will cause lower shrinkages, make parts larger, and cause tolerances to be exceeded. This is not desirable since defective items would be produced.

Each mold design is unique due to the various parameters involved such as rheology, section thicknesses and mold temperatures, which have a tremendous influence on flow behavior. Due to this uncertain nature of molding parameters many iterations may be required in prototyping a plastic part prior to satisfactory molding. This would be costly in terms of time and labor.

Plastics have a very wide field of application and the need for reliable parts has initiated a heavy competition. Any delays in manufacturing could lead to a diminished market share. Computers can be used in injection molding as databases and process controllers. The speed of computation and the reliable memory of a computer can be put to use in the design and the prototyping stages. The feature of displaying the molding process on a graphic screen can help the mold designer to evaluate a mold design before it is finalized for production to make necessary changes. Also, material usage and its economical constraints can be evaluated to perform economic analysis of the production run. Cavity filling analysis simulated on screen can provide information on molding conditions including pressures and temperatures and can show weld lines, meld lines and stresses. A weld line is a discontinuity in a molded plastic part formed by merging of two or more streams of plastic flowing together[31]. A weld line is formed across the flow. A meld line is formed in the same manner as the weld line, but it is along the flow direction. Finally, a CAD/CAM system can be coupled to numerically controlled mold cutting machines to cut the mold as per design calculations.

1.3 Feasibility of the Application of Computers in the Injection Mold Design Process

Polymer engineers and designers face many problems in manufacturing a plastic part. The complexity of the injection molding process makes a successful production start-up on the first attempt difficult. The various process parameters and other criteria such as dimensional tolerances and appearance make mold design complicated. The use of computers for the purpose of storing data collected from human experts could eliminate the number of iterations in the prototyping stage by simulating this stage and creating the mold design without making the mold. The computer integrated injection molding process is shown in Figure 1.2.

Some polymer processing operations can be simulated, and the computer skill of a computer can be used to make the heat transfer calculations and design calculations. Computers can be used to solve the algorithms for such problems and

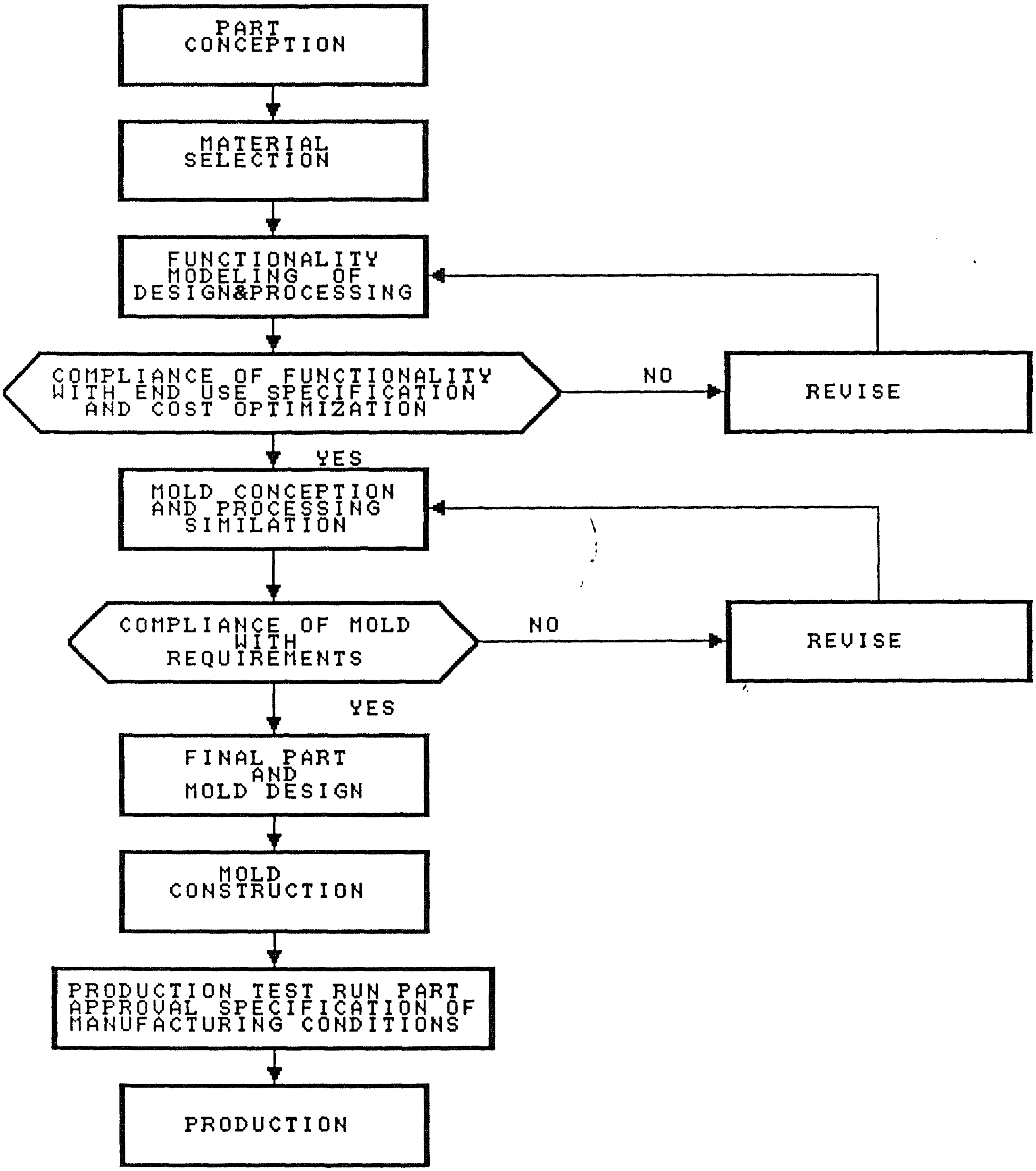

Figure 1.2: Computer integrated method of manufacturing injection molded parts

a very efficient solution can be expected for large problems. Such solutions are economically feasible and computers could be very easily adopted for such applications. The various machines that could be used are personal computers, advanced Computer Aided Design (CAD) workstations and supercomputers. There have also been rapid advances in the development, sophistication and acceptance of computational algorithms, expert systems, and artificial intelligence(AI). These are components of Computer Aided Engineering (CAE). CAE algorithms enhance the effectiveness of existing experts. The application of computers can be in the mold filling analysis, solidification analysis, economic analysis, cost analysis and for design aid packages. These features underline the feasibility of the use of computers in the injection molding process[1].

1.4 Expert Systems in Injection Molding

Injection molding satisfies many of the prerequisites of a successful implementation of expert systems. Experts in this field can perform far better than others. Since this field is vast, experts exist who have acquired a huge knowledge base that can be gained by the non-experts. Human expertise in problem solving, which is guided by a set of inference rules, can be combined with computer algorithms to give viable systems that would solve the problems efficiently and in lesser time. A knowledge base compiled with the experience and the evolving solutions to problems is used to get a wide range of solutions. The knowledge base evolved from experience is improved if the acquired expertise is stored that would otherwise be lost with personnel. Expert systems constitute computer algorithms that aim at achieving levels of performance in problem solving that matches a human expert by combining computational algorithms, inference rules and a compiled knowledge base.

1.5 Economic Justification for Computer Aided Manufacture of Plastic Parts

The relevant question that determines the justification of CAE applications is whether these tools expand the expertise of a designer in a cost effective manner. CAE packages store corporate mold design expertise and the design files, program codes and material databases are repeatedly refined and not lost with personnel. These tools can also be also used by less experienced designers to learn the design techniques. But these tools should also improve the productivity of designers and process engineers. The prime question to be satisfactorily answered by a molder is whether the use of computers would produce parts of equal quality, and cost, in a shorter prototype period. A strong commitment is required to rationalize the long and costly transition from part design to successful production. There are several programs for injection molding available for the mold designer[2]. The mold designer should make a choice from these programs by distinguishing between them for useful and good programs. The designer should have good knowledge of the injection molding process to select the program that would produce the required results. It may be necessary for the designer to select more than one program for specific applications, and integrate them.

The mold design stage requires many computer application packages to perform the functions such as analysis and drafting. This would require the designer to study many packages and this would consume a great deal of time. This training time must be offset by savings in the design time, which is difficult to do. The prototyping stage is costly because of its iterative nature. Computer programs analyze the molding problems in advance of actual operations and optimize the molding quality, hence this stage is iterative.

The CAE tools do not necessarily reduce the time to complete the design stage. On the contrary they can increase the design time. The training time to learn the associated software packages as well as the hardware costs combine to make the justification of the use of CAE tools difficult. In the second stage, a test run of the mold is made. It is usually improbable for the mold to produce a part of the required cost and quality. In most cases, the prototyping stage involves many iterations which make this stage costly. The CAE tools can eliminate the prototyping stage by simulating the iterations in shorter time to compensate for the higher expense in the design stage. Hence, accurate modeling of the mechanical, thermal and flow behavior of the polymer melts can be used in the design stage to shorten, or eliminate, the prototyping stage of the project.

1.6 Computer Aided Mold Filling Analysis

Predicting the performance of a mld without cutting any metal is a definite advantage. The simulation of the mold filling process can be used to achieve optimum conditions for making the product without cutting metal.

Mold filling is a most technically complicated and difficult phase to predict, even for an experienced mold designer, because of the uncertain process parameters. CAE is based on a solution algorithm that approximates the flow characteristics of the melt, and the mold designer can consider all factors influencing the design.

The mold filling analysis of a three dimensional part would have to be performed by describing several one dimensional flow paths and branch points. A two dimensional analysis provides information on temperature and velocity gradients transverse to the flow direction. The other parameters specified by the user are the melt and mold temperature and the injection rate. These are incorporated in the algorithm to compute the pressure drop, temperature and shear stress along the flow path with time. The position of weld lines and meld lines can be determined from the coordinates where flow fronts intersect. The pressure and temperature of the material at these flow fronts can provide information on the characteristics of the weld line.

In another type of mold filling analysis the three dimensional geometry of the mold cavity is specified as well as the process parameters. In this case the three dimensional governing equations are solved using a numerical technique such as the finite element method.

require the flowrepresentation of the filling

Numerical solutions such as the finite element method can provide an analysis of the temperature, and pressure, as the flow front advances through the cavity. Excessive fill pressures and weld line locations, and flow defects such as short shots and frozen skin formation are detected easily. The user should be able to analyze the information gathered by this method. The computation time and the cost involved is appreciable to prompt the designer to use sound judgement in such analyses.

There are many software programs that can serve the purpose of a designer[2]. Commercially available software packages include Moldflow ^{R}, TMCONCEPT ^{R}, IMES ^{R} [3] and CADMOULD ^{R}. I-DEAS Release V has developed a program for injection mold analysis[4]. The designer must study the software programs and make a choice so as to get the required results. Molding machine capabilities can also be coupled in the CAD/CAM program to obtain precise mold designs[5]. A close link between the resin supplier and the end user can be established by directly linking the design, and engineering analysis, of a plastic part with automated manufacturing using CAE[6]. Husky Injection Molding Systems, Ltd., has developed molding machine designs CAD/CAM applications capabilities. Computerized design and manufacture capabilities integrated in common databases make powerful tools that can improve injection molding efficiency and potential.

1.7 Summary

Computer aided design software in injection molding has revolutionized injection molding, in the design and manufacturing processes. Some major advantages of using CAD software in injection molding are, reduction in costs, better quality in products, increased value of products and better process control.

Theoretical equations alone do not provide accurate simulation of the complex range of variables in the injection molding process. Only a model based on experimental correlations can make a comprehensive simulation of the influence of the process variables on part quality. The parameters influencing the injection molding process such as the viscoelastic properties of the plastic, irregular mold geometries, and steep temperature gradients make prediction of the process behavior difficult. Theoretical equations only guide the nature of the behavior, but the evaluation of the variations into numerical data can be performed only by experimentation. To develop a comprehensive simulation model it would be necessary to perform molding cycle experiments, with varying part geometries and molding conditions, and store the experimental data for interpolation or extrapolation of process parameters. This technique can be adopted to develop the necessary simulation data. A finite element method can be used to analyze the model to predict pressures, temperatures and fill times.

Computer Aided Engineering can be applied to injection molding to increase the process efficiency, veduce part costs, and produce accurate parts in less time. The mold designer has many software programs to choose from to produce satisfactory mold designs from part geometries, and a correct selection can produce profitable results. The evaluation of the suitability of a CAE package is attempted by considering the value added to the parts using these techniques. Parts of equal quality produced at less cost so as to recover the higher cost anticipated in the design stage can justify a CAE application. For the successful implementation of the CAE package, it should be accurate enough to predict the process variations and the results derived from the simulation should be interpreted effectively. The package developed for the process simulation should be accurate and should account for process variations. The user should study the results from the software packages that he can use for the process simulation and select the best package.

Chapter 2

MOLDFLOW^R

2.1 Simulation of Injection Molding with MOLDFLOW

MOLDFLOW[7] programs analyze the flow of plastics into injection molds by solving simultaneously the continuity, momentum and energy equations for flow. These programs are used in two areas. One set of programs is used for mold design and is commercially important. It is used for positioning gates, dimensioning runner systems, designing flow leaders and deflectors to improve flow within the cavity. In this context the company has developed three programs that solve the situations encountered in plastics injection molding. These programs perform finite element analyses which generate information for the design of injection molds and injection molded parts. The second set of MOLDFLOW programs is used in scientific and laboratory applications. There are two programs for this purpose, a materials database and a material selection package. The input data to these programs include specific heat, thermal conductivity and density, and viscosity as a function of temperature, pressure and shear rate.

MOLDFLOW^R is a registered software of MOLDFLOW Pty Ltd., Colchester Road, Kilsyth, Victoria, 3137 Australia.

2.2 CAE Technologies in Injection Molding

The range of computerized technologies available to the plastics industry are classified as geometric technologies, database technologies, engineering technologies and manufacturing technologies.

Geometric technologies are those of solid modelling and those of drafting. Modelling technologies are used to visualize the part and check the dimensions and to check interference fits with other parts at the design stage. Modelling of a part, is used as a preprocessor for analysis programs. The drafting module replaces the manual function of drawing the part for manufacture and this module can also perform geometric calculations, e.g. intersection of surfaces, fillets, and radii between two complex surfaces in 3D. These systems can generate NC tapes to be used in the machining of molds.

Database technologies are used for material selection which have functions to search materials for particular requirements. Also, laboratory research can be performed for materials and the data stored for future use.

Computer Aided Engineering technologies help the designer in quantifying the complex relationships between variables involved in the molding process which affect the quality and the performance of the finished product. The injection molding process is simulated using engineering software to identify problems before they occur. The information needed to solve these problems is derived to optimize the process.

Manufacturing technologies help in the use of NC machining of the molds. NC machining produces complex three dimensional surfaces accurately and to the required degree of precision which would be most difficult to produce by traditional methods. Manufacturing systems can also be integrated with computers to provide a closed loop feedback of the injection molding operation. This system gives a more precise control over the injection cycle.

Management controls consist of costing systems, production scheduling programs, production control and machine monitoring. Each of these management functions can be computerized for better efficiency.

There are four major analysis technologies which could be integrated with the product design function to contribute to producing improved part quality and performance. These technologies are described in the next sections.

2.3 Database Technology

Database technologies are used for material description and selection. A database is maintained in which information on materials is stored. This helps the user in the identification and selection of materials. The user can search for specific information on material properties and grades. The user can determine the suitability of a grade for a given application. This can establish limitations and capabilities of materials that can be stored for future reference. There are also options to rank the priorities of various material characteristics during the selection process. Certain databases are linked with analysis programs that are intelligent, in the sense that they store the material characteristics as functions rather than points. Hence, if a property requirement is required, it searches the database using interpolation or extrapolation functions between defined points. For instance the user can run an analysis program with specific requirements for material conditions as demanded by the part design. The program would then search the database for stored data points and use a function depending on known behavior of particular properties to generate specific data. This prediction of data is incorporated in the algorithm of the program. Accurate prediction of material properties necessitates a database with specific and reliable data. The complex and variable behavior of polymers and the influence of the molding process on the properties of materials is recorded in the MOLDFLOW database. Figure 2.1 illustrates the use of search techniques.

The physical properties of materials are recorded by laboratory testing procedures under injection molding conditions. The results of these tests are correlated with established relationships of behavior to classify into different types. The data is verified through classification designations which classify the materials reliably.

The system has been designed to expand the amount and type of data and store in files by running a MOLDFLOW program, MATDB. This program is run by a command language, unlike other MOLDFLOW programs. Instructions are entered into the program by the user in a logical sequence of commands which resembles a sentence of speech. The data structure is designed to accommodate further enhancements in commands. This storage system renders concise data files and reduces the risk of wrongly entered data. The data can be accessed easily and fast. This system can be used for CADAM software that performs stress analysis and shrinkage analysis.

The material data collected from material suppliers is stored in a file called, the standard database. There is also an option to store the users own data in a personal database which can be modified by the user according to specific requirements. The information in both the databases has material file names, material grades and material data. The material file names consist of names of groups of material grades which is generally a suppliers name. The material grades are described in each of the files with a description of properties, variables and points.

Material data in the new database is stored in point descriptions and data required for specific points in the analysis software is derived from material characteristic equations. For example, viscosity is characterized by the power law equation,

```
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Search string "MPPO" not found on < Moldflow Standard Database

>>SE STR='PPO'/LOG


MATERIAL FILE NAME < Moldflow Standard Database >
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GEPEUR
Material Grade Description    ( Searching="PPO" )
---------------------------
 N1000 PPO NORYL 110 MOD STANDARD GRADE            VI(280)145
 N1001 PPO NORYL N110S MOD  FDA GRADE              VI(280)145
 N1002 PPO NORYL N110HG MOD  HIGH GLOSS            VI(280)145
 N1003 PPO NORYL EN110 MOD  EXTR GRADE             VI(280)145
 N1010 PPO NORYL 731 MOD STANDARD GRADE            VI(300)200
 N1011 PPO NORYL 731S MOD 731 FDA GRADE            VI(300)200
 N1012 PPO NORYL EN130 MOD 731 EXTR GRADE          VI(300)200
 N1020 PPO NORYL SE1 MOD STANDARD V1 GRADE         VI(300)202
 N1021 PPO NORYL SE0 MOD STANDARD V0 GRADE         VI(300)202
 N1022 PPO NORYL ENV125 MOD SE1 EXTR GRADE         VI(300)202
 N1023 PPO NORYL PX1105 MOD ELECTRICAL GRADE       VI(300)202
 N1024 PPO NORYL PX1107 MOD PX1105 10%GLASS        VI(300)202
 N1030 PPO NORYL SE90 MOD STANDARD GRADE           VI(280)146
 N1031 PPO NORYL ENV90 MOD SE90 EXTR GRADE         VI(280)146
 N1032 PPO NORYL FN215D MOD STAND FOAM GRADE       VI(280)146
 N1040 PPO NORYL SE100 MOD STANDARD V1 GRADE       VI(280)203


 N1042 PPO NORYL ENV100 MOD SE100 EXTR GRADE       VI(280)203
 N1050 PPO NORYL GFN1 MOD STAN GRADE 10%GLASS      VI(280)170
 N1051 PPO NORYL FN5110 MOD FOAMGRADE 10%GLASS     VI(280)170
 N1052 PPO NORYL GFN1SE1 MOD GFN1 V1 GRADE         VI(280)170
 N1053 PPO NORYL PX1715 MOD SP GRADE 15%GLASS      VI(280)170
 N1060 PPO NORYL GFN2 MOD STAN GRADE 20%GLASS      VI(300)180
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 N1081 PPO NORYL PX1134 MOD IMPMOD GR COLOURS      VI(290)200
 N1090 PPO NORYL PX1180 MOD IMPMOD GR BLACK        VI(290)145
 N1091 PPO NORYL PX1181 MOD IMPMOD GR COLOURS      VI(290)145
 N1092 PPO NORYL PX1181 MOD BLOWMOULDING GRADE 220C BOZDATA
 N1200 PPO NORYL GTX900 MOD ONLINE PAINTING GRADE (285C)BOZDATA
 N1201 PPO NORYL GTX901 MOD PRELIMINARY DATA BOZDATA
 N1202 PPO NORYL GTX910 MOD PRELIMINARY DATA  BOZDATA
 N1210 PPO NORYL GTX810 MOD 10% GLASS FILLED GRADE (285C)BOZDAT
 N1220 PPO NORYL GTX820 MOD 20% GLASS FILLED GRADE (285C)BOZDAT
 N1230 PPO NORYL GTX830 MOD 30% GLASS FILLED GRADE (285C)BOZDAT
```

Figure 2.1: Material search for modified polyphenylene oxide in Moldflow database, MATDB

$$Viscosity = A * (shear\ rate) * B * \exp(C * Temp) \tag{2.1}$$

Viscosity data of new materials in the database is represented by a power law relation. The data for the material is stored as three points of viscosity, each point having the coordinates of temperature, shear rate and viscosity. The parameters A, B and C are derived from laboratory testing procedures. The power law is calculated whenever required in any analysis software. This relation is called a first order viscosity characterization. A second order characterization is,

$$Y = A_1 + A_2 * X + A_3 * Z + A_4 * X * X + A_5 * X * Z + A_6 * Z * Z \tag{2.2}$$

where, $Y = \log(viscosity)$

$X = \log(shear\ rate)$

$Z = temperature$

The data for this equation is stored in six points of temperature, shear rate and viscosity.

Each material grade can be described by any number of properties. Each property can be dependent upon any number of variables and each variation can be described by any number of points. This data point structure of the database renders it general and versatile. The advantage of this system is the ability to change mathematical models. For a new model the point structure would have to store only the relationship between the coefficients whereas a database storing coefficients only would have to store more information relating coefficients to types of models. The point structure database exists as a filing system and is simpler to maintain and easier to access for the analysis software.

A standard list of material properties has been prepared to classify and manipulate data. The properties and their associated variables in the list can be extended when required. The standard properties listed are conductivity, specific heat, density, freeze temperature, no flow temperature, viscosity, gel time, tensile modulus, Poisson's ratio, degree of crystallinity and degree of orientation. Each of properties has a set of variables. This system can be expanded to describe the complex performance of many polymer properties. Thus the database can more precisely predict, and quantify, material performance in specific applications. The computer printout of a list of materials and a list of properties of modified polyphenylene oxide (MPPO) nylon resin is shown in Figure 2.2.

2.4 Flow Technology

The MOLDFLOW programs consider the dependence of viscosity of plastics on temperature and shear rate to calculate viscosity at a point and predict pressure distribution. Viscosity, temperature and shear will vary depending on the flow rate. Also, flow rate varies with viscosity. Thus flow and viscosity are interlinked. The programs analyze single sections to predict pressure and temperature over the sections and this analysis is extended to develop a total mechanism to predict pressure, temperature and flow patterns in a complex molding.

These programs solve the mathematical equations of heat transfer and fluid flow using a finite difference scheme. Flow paths are defined by simple strip geometries which are broken into sections. These sections are divided into a number

```
MATERIAL FILE NAME < Moldflow Standard Database >
=================
GETEMP
Material Grade Description    ( Searching="PPO" )
--------------------------
P1000  PPO    NORYL SE 100           GE                      VI(300)178
P1002  PPO    NORYL 534-701          GE                      VI(300)238
P1003  PPO    NORYL PX-17180-780     GE                      VI(300)209
P1004  PPO    NORYL 731-701          GE                      VI(300)365
P1005  PPO    NORYL 110-701          GE                      VI(300)168
P1006  PPO    NORYL SE1-701          GE                      VI(300)238
P1007  PPO    NORYL SEO-701          GE                      VI(300)204
P1008  PPO    NORYL GFN3-701         GE                      VI(300)359
P1009  PPO    NORYL GFN3-SE1         GE                      VI(300)340
P1010  PPO    NORYL GFN2-801         GE                      VI(300)271
P2001  PPO    NORYL N-190            GE  PLAC TESTED         VI(300)89
P2002  PPO    NORYL PN-235           GE  PLAC TESTED         VI(300)118
R1709  PPO    NORYL PX 1039 Y2237    GE                      VI(300)215
R1710  PPO    NORYL PX1039Y 3106     GE                      VI(300)245
R5201  PPO    NORYL PX1112 701       GE                      VI(300)236


        ...(  Search Completed on string="PPO" )...



>>INSPECT FIL='GETEMP' CODE='P1000'/LOG

MATERIAL FILE NAME < Moldflow Standard Database >
=================
GETEMP
Material Grade Description
--------------------------
P1000  PPO    NORYL SE 100           GE                      VI(300)178
Material Grade Data
==================
CONDUCTIVITY        J/(m.sec.degC)  ==>   0.100
SPECIFIC HEAT       J/(kg.degC)     ==>   2050.
DENSITY             kg/cu.m         ==>   1000.
FREEZE TEMPERATURE  degC            ==>   150.0
NO-FLOW TEMPERATURE degC            ==>   180.0

VISCOSITY
---------
TEMPERATURE         |SHEAR RATE          |VISCOSITY
degC                |1/sec               |Pa.sec
    280.0           |    100.0           |    1491.
    300.0           |    1000.           |    178.0
    310.0           |    1.000e+04       |    24.36
```

Figure 2.2: Material listing in Moldflow database, MATDB and properties of modified polyphenylene oxide

of slices having their own temperature, shear rate and viscosity. The normal heat transfer equations are used to calculate the heat transfer into each slice and the flow is analyzed by solving the flow equations by numerical integration over the section.

A significant amount of computer power is required to run these programs. Near the frozen layer, conditions of high shear and low temperature prevail, and the experimental results are most prone to error, rendering the results very dependent on the analysis in this region. These schemes work well in most applications but the development of simpler algorithms based on dimensionless analysis and curve fitting schemes results in more practical systems.

For an isothermal flow, first the shear rate is calculated and then the viscosity based on shear rate and temperature. This viscosity is used in standard mold filling calculations. In a practical situation hot plastic flows into a cold mold leading to a frozen skin formation. Hence, the thickness of the frozen layer should be calculated and then the effects of temperature distribution across the channel should be determined. This problem is solved by introducing dimensionless analysis.

2.4.1 Dimensionless Analysis

In dimensionless analysis two dimensionless factors are required, one for temperature and the other for time. Each of these values should vary from 0 to 1. The dimensionless temperature factor, TEMD, is defined as

$$TEMD = \frac{T_{melt} - T_x}{T_{melt} - T_{mold}} \tag{2.3}$$

where, T_x is the temperature at point x.

The dimensionless time factor, TIMD, is derived from the ratio of residence time of the element to the cooling time within a particular element. Thus if

$$c_t = \frac{(Residence\ time)}{(Cooling\ time)} \tag{2.4}$$

This can be scaled within the range of 0 - 1 by the following formula.

$$TIMD = 1 - \exp(-c_t) \tag{2.5}$$

If the residence time is zero then TIMD is zero which gives a uniform temperature profile across the section. If the residence time is very long compared to the cooling time then TIMD becomes 1 and the temperature profile across the section becomes the equilibrium value.

Assuming that the rate of change of temperature is constant across the section and that T_{melt} and T_{mold} are known for the dimensionless factor, the relation that defines the temperature at any point across the section would be

$$\frac{d^2T}{dn^2} = K \tag{2.6}$$

The temperature at the center, T_c can be obtained by assuming a logarithmic cooling relation and accounting for heat generated by friction. Thus,
(Temperature at center) = (original temperature at center) - (heat lost by conduction) + (heat generated by friction)

$$T_c = T_{melt} - K_1 * \exp(K_2 * time) + T_{friction} \tag{2.7}$$

where K_1 and K_2 are the logarithmic cooling factors. This relation would evaluate an equilibrium temperature distribution as time tends towards infinity. If a dimensionless time factor is introduced in this relation, a temperature profile at any point can be created by using a set of formulae. The Fig.1 shows the graph of temperature distribution as a function of time and temperature.

The flow equation relating pressure, viscosity and section geometry is as shown,

$$P = Q * V * \frac{12b}{wh^3} \tag{2.8}$$

where,

V = viscosity

Q = flow rate

P = pressure

w = width

h = thickness

and A, B, C are constants in first order material viscosity relation. This would require the values of viscosity to be known. Viscosity is related to shear and temperature as follows.

$$V = A * (shear)^B * \exp(C * temp) \tag{2.9}$$

The thickness of the frozen layer can be calculated by defining a no-flow temperature and from the temperature distribution profile. A nominal shear rate is then calculated based on the effective flow rate in the channel by the equation,

$$shear\ rate = \frac{Q * 6}{wh^2} \tag{2.10}$$

The effective temperature is located at a point between the center of the channel and the frozen layer. Thus from the temperature distribution, viscosity can be calculated and the standard flow equations can be solved to conduct a flow analysis.

2.4.2 Analysis of Actual Moldings

In actual moldings a branching flow technique is used wherein flow originates at an element and divides into a number of flow paths. Each of the paths can further divide into any number of paths. Figure 2.3 shows a simulated branching flow in a mold designed to produce the parts of a digitizer *mouse*. The design illustrates a method to mold all the components in a single mold. Thus flow is a series of elements which continuously divide into a number of diverging flow paths. Though the flow rate of each section is not known, we know by the law continuity that flow rate into each section must equal the flow rate out of each section. This gives a boundary condition from which the flow pattern can be calculated. This system can be used to balance flows, for conducting quick checks on moldability and for automatic dimensioning of runners. The disadvantage with this system is that the user must define the flow direction which might not be easily possible for a complex molding. This has lead to the development of finite element schemes.

The MOLDFLOW finite element scheme works by a series of meshes as the mold is filled. A meshed computer *mouse* plate is shown in Figure 2.4. This method predicts the mold filling pattern efficiently. In the 3-D flow analysis the geometry is defined, material is selected and the molding conditions are specified.

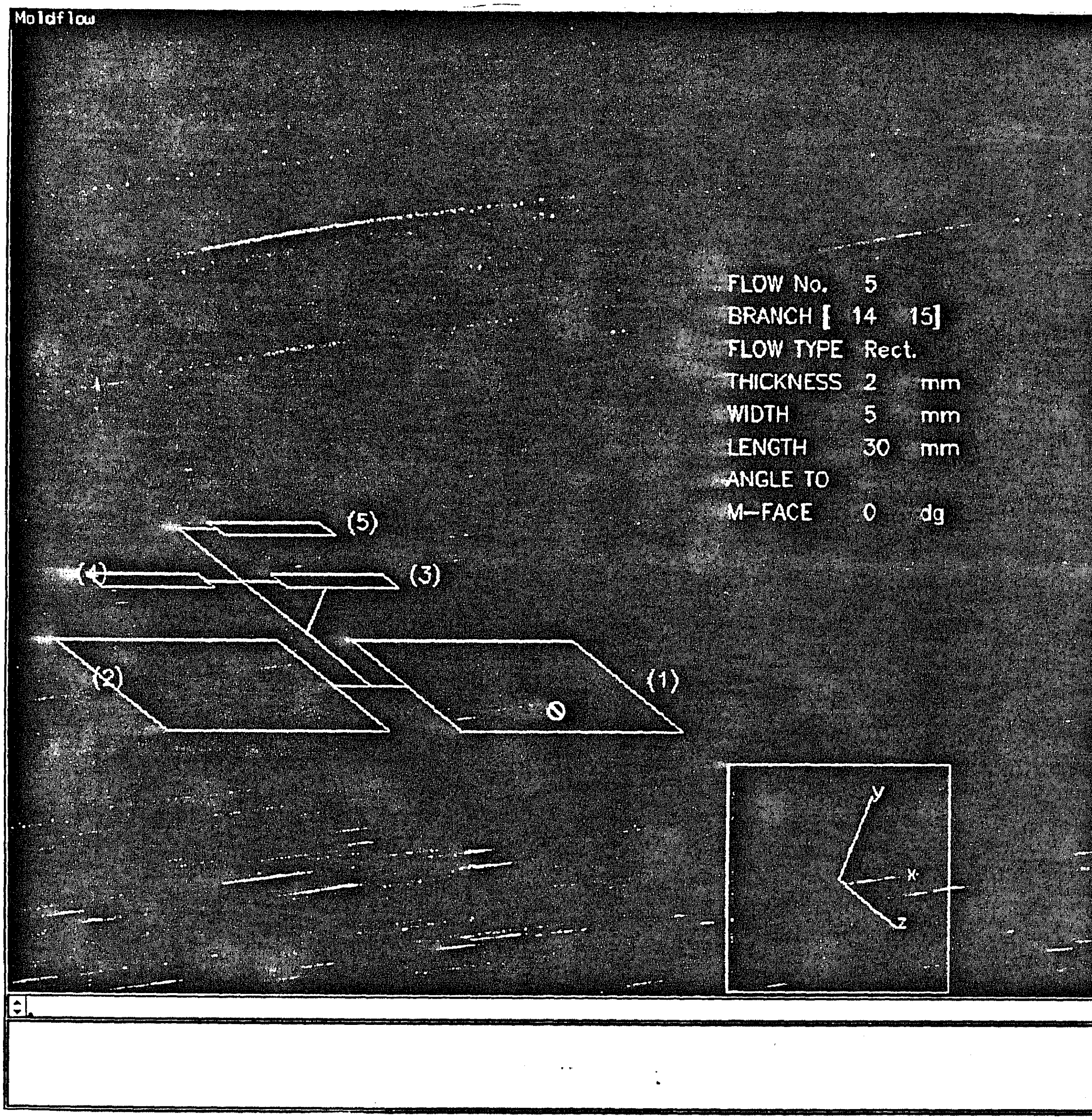

Figure 2.3: Branching flow in the mold designed for a computer mouse.

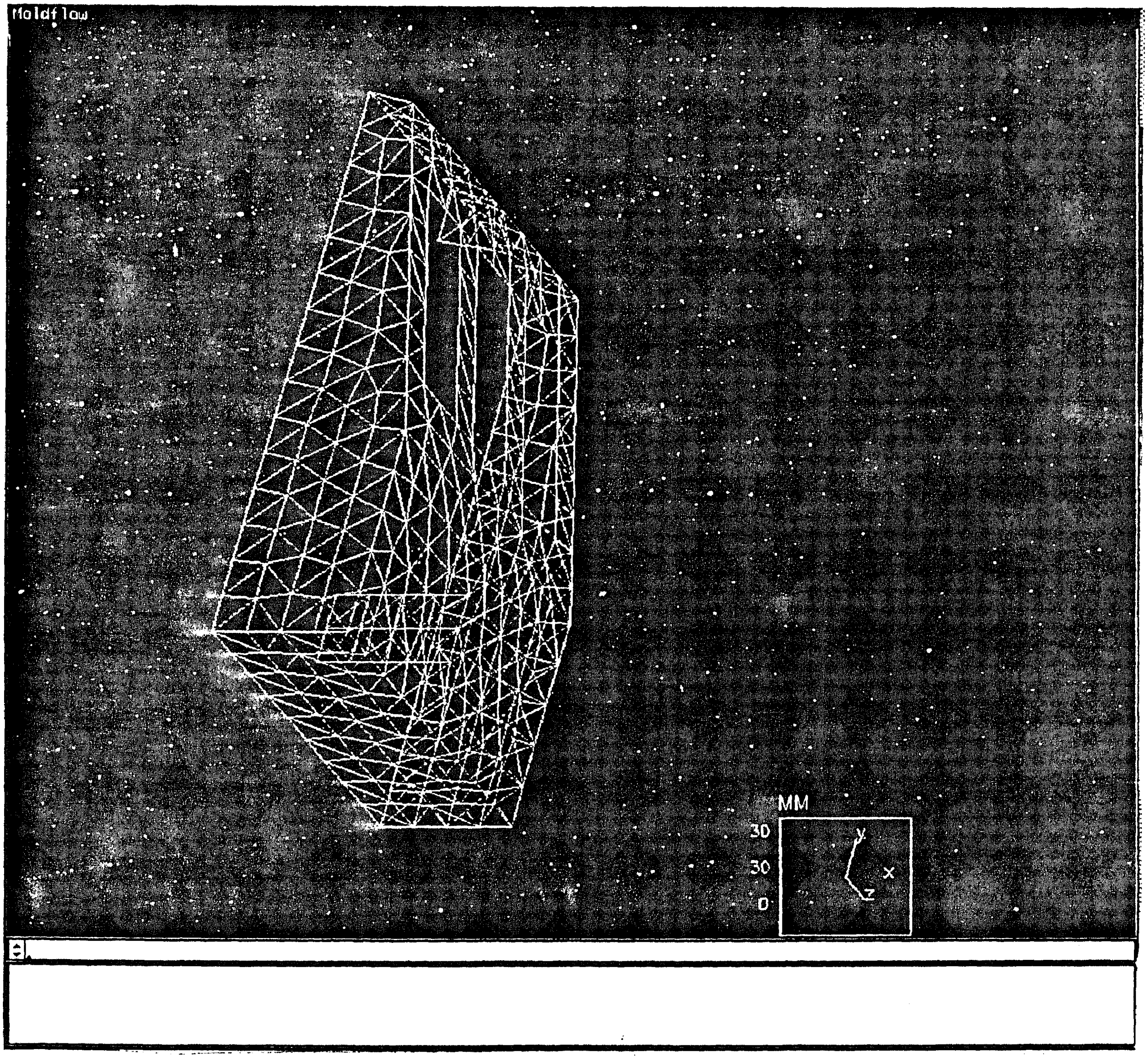

Figure 2.4: Model of computer mouse meshed using FMESH

The program then calculates the filling pattern in a series of steps, and predicts pressure drops over sections, temperature changes in the flow front, cooling times, pressure required for mold filling, shear stress and shear rates. Results are presented in a color graphics format showing filling pattern development the direction of flow and the position of weld lines and meld lines is known. Figure 2.5 shows the pressure distribution in the *mouse* plate, the temperature distribution is shown in Figure 2.6 and Figure 2.7 shows the filling pattern of the mold.

2.5 Integration of Technologies

MOLDFLOW has developed three processing programs which integrate the functions of processing and displaying geometric data.

SMOD is a wire frame model generator which is used to create the geometric model for use in the finite element analysis programs. The part geometry can be defined and the part can be displayed on a computer screen. The model is ready to be meshed by the FMESH program. SMOD is driven by a command language and the information is stored in three files having the general model information, point coordinate information and surface information.

FMESH is an automatic mesh generator suitable for all kinds of surfaces. It can read SMOD files and ASCII files created from the keyboard. FMESH is driven by a command language. The mesh density can be controlled by defining the number of divisions across the model. The mesh can be generated across a curve so that it can create a 3-D faceted surface without defining a multitude of surfaces.

FRES displays the simulation of flow, temperature distribution, cooling and stress patterns. Thus it displays isobars, isotherms and isochrones. Isobars are lines that join points at equal pressure, isotherms join points at equal temperature and

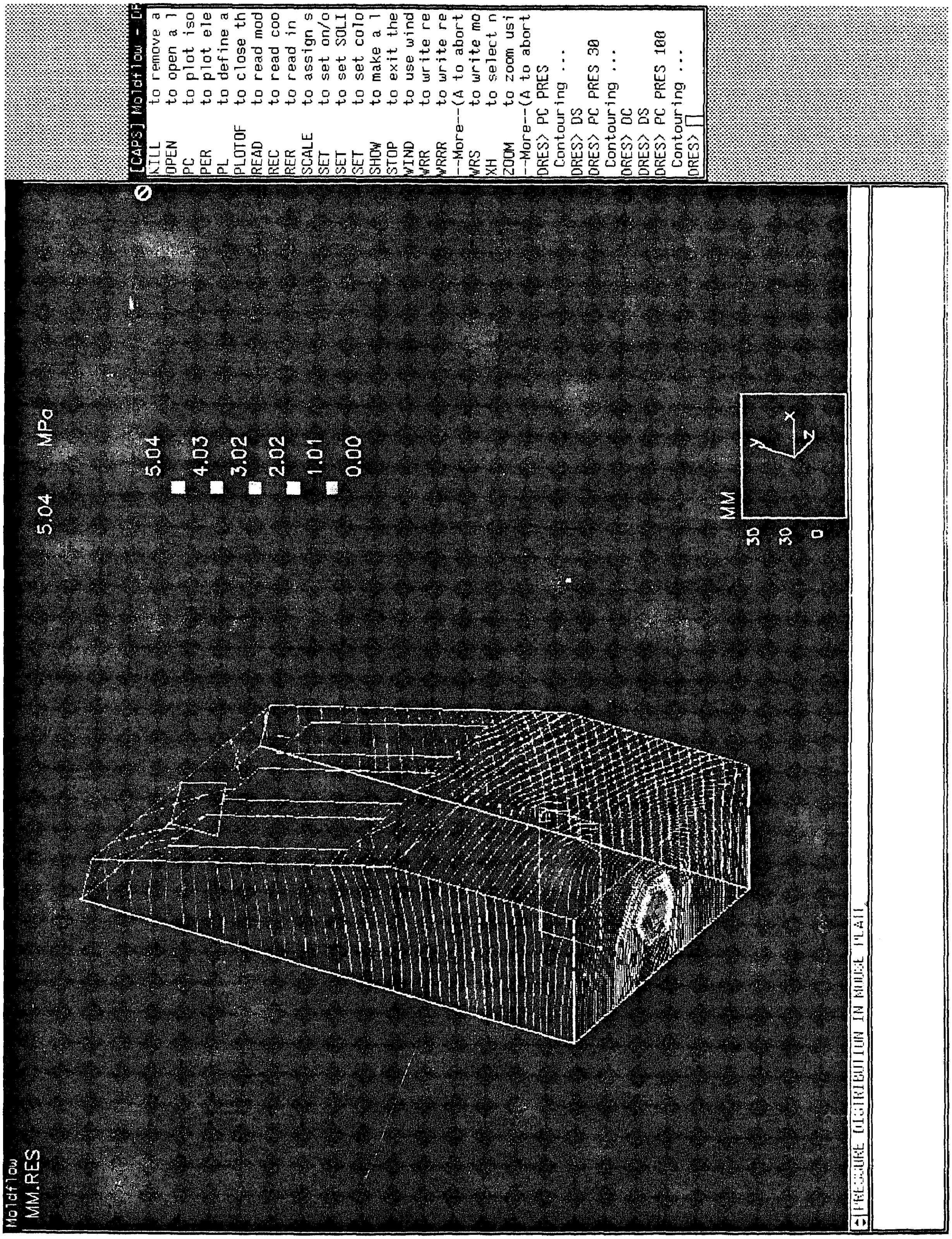

Figure 2.5 : Pressure flow simulation in the mold for a computer mouse.

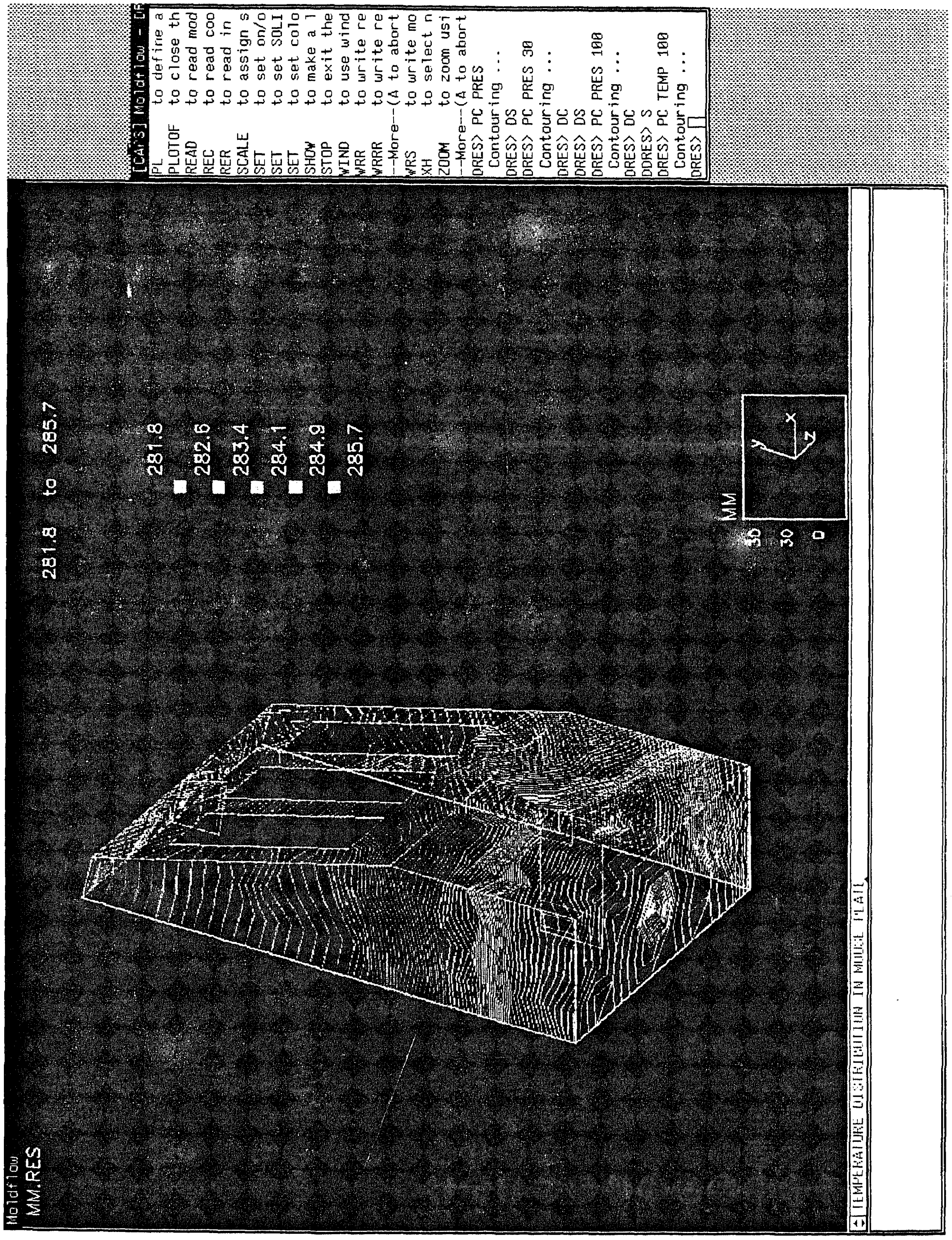

Figure 2.6: Temperature distribution in the mold for a computer mouse.

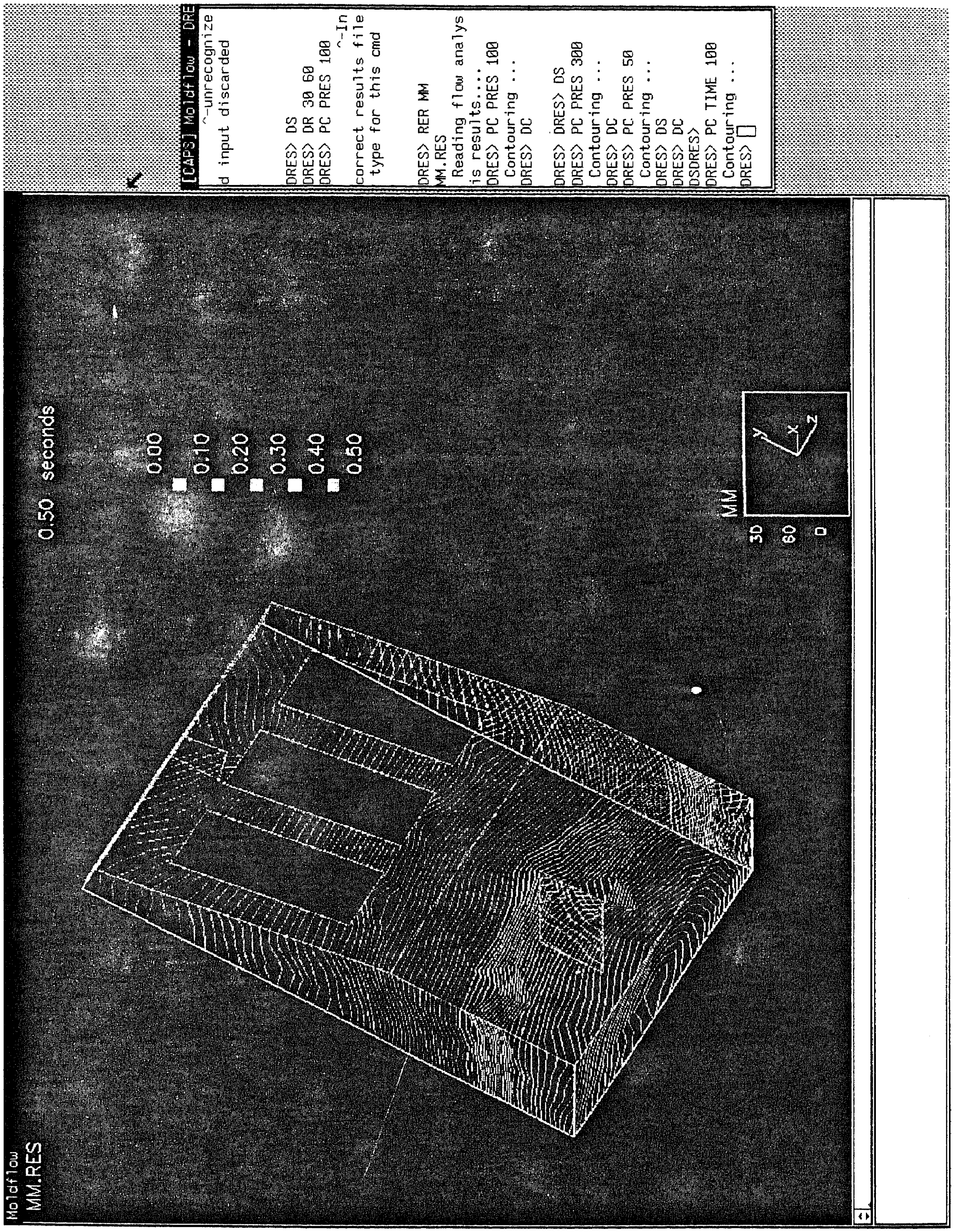

Figure 2.7: Cavity filling pattern in the mold for a computer mouse.

isochrones simulate short shots by joining points that are filled at the same time interval.

2.6 MOLDFLOW Analysis Features

MOLDFLOW is a CAD software that attempts to model the injection molding process by using finite element methods and simulating techniques, to provide an interactive graphics package. The program effectively simulates the cavity filling process that predicts part dimensions and properties before manufacturing the part. Thus the part designer knows the outcome of the design and any changes that may be required can be made in the design stage. The prototyping time and cost is almost eliminated, thus reducing part cost and cycle time. The disadvantage that some molders find is that initial cost of the software is much. This software does not consider shrinkage into account when designing molds. It can be interfaced with solid modeling design software and CAD/CAM systems.

MOLDFLOW Thermoplastic and Thermoset Flow Analysis has the following features :

- Flow Analysis : The programs consider the heat transfer and flow dependence on shear and temperature to calculate viscosity and predict pressure distribution. In mathematical terminology, simultaneous equations of heat transfer and fluid flow are solved.

- Project Planning : This helps in approaching individual MOLDFLOW projects.

- Modelling : This part of the software helps to select the right modelling approach.

- Materials Selection : The package maintains a database of materials which is used for mold design and research.

- CAD/CAM Interface : This part helps in interfacing Computer Aided Drafting Systems with MOLDFLOW.

Chapter 3

TMCONCEPT^R

TMCONCEPT is a set of computer programs for injection molding. This chapter explains the fundamentals of these programs and about their application and integration to optimize a plastics part design. The aims for the design of a part from its conception to production are to produce a part of acceptable quality, to reduce the lead time involved in mold making, to design an economic mold and to achieve production flexibility in the processes. Each of the variables mentioned above influences all of the others. It is necessary to manage these conditions and integrate these models to optimize the design.

The TMCONCEPT system works on the principle of integration of objectives. There are different databases for the different objectives but the program logic integrates the various system components. The TMCONCEPT system models the entire injection molding process and the economic aspects are given due consideration when evaluating the technical aspects leading to a true optimization.

The approach adopted by TMCONCEPT is called an *Expert/System* because it aims to put the best available technology at the disposal of the user. This

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TMCONCEPT^R is a registered software of Plastics & Computer Inc., Montclair, NJ, USA.

system is quantitative in nature because it integrates the scientific calculations based on the mathematical solution with the practical knowledge and experience. Thus priority is given to the needs of the industry rather than the accuracy of the mathematical solution and it is thus different than the traditional approach.

3.1 TMCONCEPT : Program features and applications

To optimize the quality-cost relationship, the following component program packages are used:

- TMC-MS package for material selection
- TMC-MCO package for molding and cost optimization
- TMC-FA package for mold filling analysis
- TMC-CSE package for cavity dimensioning
- TMC-MTA package for mold thermal analysis

The strategy for analyzing a molding operation depends on the objectives that are to be met and on the problems posed by the particular molding. Some aspects may be overlooked and this could lead to unnecessary costs. TMCONCEPT is structured so that it compels the user to consider the need for each specific step in a logical sequence. TMCONCEPT is fully menu driven so that the user can easily follow a sequence of steps for analyses. An on-line help facility is available by which the relevant sections of the user manual can be accessed. The TMCONCEPT programs also allow the user to choose any set of dimensional units as well as the language in which he wants to work including English, Italian and German.

To save unnecessary effort, TMCONCEPT offers solutions at different levels of analysis. All analyses begin with a very rapid first approximation. This determines the general feasibility of the operation and decides the appropriate operating conditions. If the user needs to refine the analysis, the next level can be entered to complete the additional inputs and compute the best solution to the problem. Coherence checks of user input are another highly useful feature of the TMCONCEPT programs. These checks are provided to catch human errors in data entry. A comprehensive molding analysis could be guided by a study based on molding requirements, based on certain factors such as material properties, mold geometry, process variables and and cost constraints. TMCONCEPT has a set of software packages that could be used to satisfy these requirements.

The first task for a full analysis of a design concept is the selection of the best material to be used. TMC-MS selects the best material on the basis of end use requirement by using rating classifications, and a cost index per desired property. A differentiation in materials according to processability can be carried out using the TMC-MCO package for molding and cost optimization. The following description of the routines is illustrated by a demonstration analysis in which the part to be molded is also shown.

In the first step of the TMC-MCO analysis, the MCO1 program quickly makes the FIRST PRACTICAL OPTIMIZATION and establishes the EASE OF MOLDING to specified part tolerances. The second program, MCO2, defines the SINGLE CAVITY MOLDING SPECIFICATIONS and provides a complete moldability analysis. The molding conditions are improved to determine the components of the molding cycle, and the holding pressure, based on the part geometry, designed tolerances (PART QUALITY), gate specifications and known process fluctuations. To optimize the quality-cost relationship, we must consider cost aspects at an early stage to meet the total design approach. In the third step, MCO3, a PRACTICAL MOLDING AND COST ANALYSIS is made. The molding machine is selected and the optimum number of cavities are computed, based on cycle time, which includes mold opening, ejection and closing times of the molding machine. Different cost figures may result for different materials and this is used to further narrow the material selection. Machine and mold constraints, if any, are identified. Alternate solutions are suggested by displaying the economic consequences of each constraint. For example, assume that the clamping force for filling requires a large machine. Multiple gating may reduce clamping requirements. The program can identify potential cost savings, before the evaluating the technical feasibility of multiple gating.

The TMC-FA package performs a deeper mold filling analysis. It determines the best filling condition and defines the moldability window. The program is also used to position the weld line and to determine the quality of the weld and the available time for packing. The program can also optimize the dimensions of the sprue and runner system so as to minimize the material usage. In addition to balancing the flow paths for pressure, the program also balances the average temperature, frozen skin formation and maximum temperature attained in the cross section of the flow path. It simulates runnerless molding, considering the effect of cycle non-filling time on the temperature of the material in the internally or externally heated runner system. It also simulates the flow rate control during filling and models the operation of microprocessor programmed injection. Thus the flow rate profile can be controlled at any location along the flow path.

Next, the TMC-CSE package can be used to design the cavity to compensate for shrinkage. It considers the flow orientation, tool making quality that decides the mold tolerances, and the contour of the mold (male/female). This establishes a direct relationship between part dimensions with their respective tolerances, mold

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MCO1 - MOLDABILITY : FIRST APPROXIMATION

< 1 > RANGE OF COOLING TIMES VS WALL THICKNESS
< 2 > TOLERANCE LEVELS VS PART DIMENSION
< 3 > INDICATION OF MAXIMUM FLOW LENGTH VS THICKNESS
< 4 > INJECTION PRESSURE AND CLAMPING FORCE
< 5 > OPERATIVE CONDITIONS
< 6 > NEW ANALYSIS
< 7 > PROGRAMS MENU

< MAT - M200 / DEMOUSA >

------------------------ Select number (? = help) -----------

< ENTER > to confirm ---------------- < SPACE BAR > to c

[MCO1 - table 3]

Plastics & Computer   TMconcept-MCO for molding optimiza

MCO1 - MOLDABILITY : FIRST APPROXIMATION

RANGE OF COOLING TIMES VS WALL THICKNESS [1 - 8 mm]

MATERIAL FILE : MAT - CODE : M200 - FILE DESCRIPTION : ACETAL HOMOPOLY

Excluding molding machine cycle components and ejection problems;
A: Lowest quality B:Best quality AVG. average quality

MOLD TEMPERATURE [60 - 120] C 65

THICKNESS mm	A: REQ COOL. s	B: REQ COOL. s	AVG
2.000	9.5	12.8	11.1
3.000	17.8	24.3	20.8
4.000	27.7	38.3	32.6

A: REQ COOL. s 27.7 B: REQ COOL. s 38.3 AVG s 32.6

Figure 3.1: First practical approximation

TMconcept-MCO for molding optimization : MCO3 - PRACTICAL MOLDING AND

PRACTICAL MOLDING AND COST ANALYSIS FILE : DEEPAK FILE DESCRIPTIO
SETUP FILE : DEMOUSA FILE DESCRIPTION : Illustrative US plant an
MATERIAL FILE : MAT - CODE : M200 - FILE DESCRIPTION : ACETAL HOMOPOI

PART PARAMETERS :

QUALITY < I=Industrial E= Aesthetic >		I
PART VOLUME	cm^3	23.1
MAXIMUM THICKNESS	mm	4
WEIGHTED AVG. THICKNESS	mm	3.16
section near the gate	:	
THICKNESS	mm	4
MINIMUM WIDTH	mm	30

MOLDING PARAMETERS :

SINGLE MOLDING MACHINE	:	N
INJECTION TIME	s	2.18
PACKING TIME	s	17.28
COOLING TIME	s	45.51
COMPUTED CYCLE TIME	s	47.68
TIME LEFT FOR PLASTICATING	s	28.23
CYCLE DEAD TIME < 0 - n >	s	.5
Single cavity - PROJECTED AREA	cm^2	38.5
Single cavity - CLAMPING FORCE	Ton	28.31671
FILLING PRESSURE	bar	1000
HOLDING PRESSURE	bar	750
AUTOMATIC MOLDING <Y/N>	:	Y
MACHINE OPERATORS < 0 - n. >	n.	0
MOLDING HOURS PER DAY		16
DAYS PER WEEK		5

MOLD PARAMETERS :

SINGLE CAVITY INSERT DIMENSION	:	
Horizontal	mm	100
Vertical	mm	80
FRONT + REAR CAVITY-PLATE HEIGHTS	mm	150
NUMBER OF MOLD CAVITIES	n.	8
MAX. THEORETICAL CAVITIES LAY-OUT	:	
Horizontal	n.	2
Vertical	n.	8
DISTANCE BETWEEN CAVITY INSERTS	:	
Horizontal	mm	25
Vertical	mm	25
SPRUE LENGTH	mm	70
AVG. RUNNER LENGTH PER CAVITY	mm	70
MIN. MOLD OPENING FOR EJECTION	mm	105

Figure 3.2: Practical molding and cost analysis

dimensions with their tolerances, and molding conditions with their permissible fluctuations.

The TMC-MTA package for mold thermal analysis performs the heat exchange calculations and quantifies the heat to be removed from the mold to maintain the mold surface temperature within specified limits. It also considers the part quality in this computation. Also, since shrinkage is dependent on mold temperature, and tolerances are the result of variations in shrinkage, it becomes necessary to identify the dimensions that ought to have close control of mold temperature. This is a feature of this analysis.

The final solution is a set of optimized cost figures obtained from the PRACTICAL MOLDING AND COST ANALYSIS(MCO3). This analysis provides specifications for material selection, molding conditions, mold filling conditions, mold dimensions and their optimal tolerances, mold thermal conditioning specifications and cost and production planning data. The TMCONCEPT package is very comprehensive with an accurate set of models that simulate the injection molding process.

3.2 The TMC-MCO program package

The TMC-MCO package for molding and cost optimization correlates the design, quality and cost of the part to the molding process. The program is supported with a library of data acquired from a number of industrial moldings including material, part design, mold design, processing variables, machine characteristics and cost constraints. This feature of the program renders itself suitable for practical applications. The package comprises three programs that refine the analysis in steps from a first approximation. The MCO1 program makes an approximation of the mold based on the geometry of the part and the material used. It determines approximate values of the molding cycle time, tolerances attainable, the injection pressure and the clamping pressure. The program MCO2 considers the gate design and location, orientation of the part with respect to the mold surface, holding pressure and mold temperature to determine the estimated cycle time, estimated injection time, screw forward time and suggested mold tolerances. The program MCO3 accounts for economic and cost factors, production requirements and plant operating conditions to calculate molding cycle time, molding pressures, number of cavities, optimum batch size and material, processing and tooling costs. The user gets a complete simulation of the process including economic parameters for molding the part.

The user can also change the economic and equipment parameters that guide the simulation of the molding process, by changing the SETUP files. SETUP files store data on machine parameters and molding conditions specific to any particular plant location. The machine variables defined in the files include labor costs, productivity standards and financial costs. The molding variables include platen size, clamping force, plasticating capacity, injection capacity, injection pressure and its fluctuation.

The program stores a material database that describes major thermoplastic resins. The variables of the resins stored in the database include density, thermal expansion and variables that correlate the molding conditions to the mold design such as the non-linear relation between holding pressure and shrinkage for any mold temperature and part thickness. The user can update this database thus incorporating his/her own experience. There is a test procedure that should be followed by the user to gather material data.

3.3 The TMC-CSE program package

The TMC-CSE program package computes mold dimensions and their tolerances considering various parameters. The user notes the part dimensions and their tolerances in the part drawing and sets the tool making tolerances. Material shrinkage affects the part dimensions and it depends on many factors such as part geometry, flow orientation, mold variables and molding conditions such as gate location and dimensions and post-molding dimensional change. The programs relate shrinkage to these variables and part quality. TMC- CSE should follow an analysis with the MCO2 Moldability program of the TMC-MCO package to obtain the best and most comprehensive shrinkage analysis in order to consider the complex interactions of these variables. The molding conditions assumed by the CSE program are within the window of moldability defined by the TMC-MCO program. The direct interaction between CSE and other programs makes this analysis fairly accurate in computing tolerance and shrinkage data. The shrinkage analysis that needs to be performed without support from any other program of the TMCONCEPT system, the CSE1 and CSE0 programs could be used. The programs calculate the allowable minimum and maximum shrinkage for any dimension. The program suggests manageable tolerance levels when the allowable limits are close.

Any shrinkage analysis starts with a CSE0 program. This program sorts and classifies part dimensions based on the type of tolerance so as to assure that all dimensions requiring a degree of precision are analyzed appropriately. The tolerances on the part can be specified as critical dimensions having functional constraints or specified as general tolerances on the part drawing. The program identifies dimensions with sufficiently wide tolerances for which shrinkage allowances are not necessary. This is the first of the three levels of computation that the program identifies. Cost savings in such case may be possible by relaxing the tool making tolerances. Also, dimensions that would be difficult to machine due to the need for non-standard tools can be avoided. CSE0 analyses compute with the data created during a preceding MCO2 analysis. The next level of computation identifies the range of dimensions for which analysis with average shrinkage values is sufficient. Thus the user can save the effort of analyzing each dimension with the MCO2 program. The user determines critical dimensions requiring a precise MCO2/CSE2 analysis that is performed in the third level of computation with computed shrinkage values.

The CSE1 program is independent of other TMCONCEPT programs. It computes mold dimensions with tolerances, allowable range for shrinkage values and part dimensions and tolerances after molding. The program computes mold dimensions and tolerances with a precision that is unattainable with traditional methods. The direction of part tolerance and the contour of the mold surface is considered.

The CSE2 program calculates cavity dimensions with shrinkage values computed by the MCO2 program. The computation is based on shrinkage for specific part geometries, mold design and molding conditions such as holding pressure, mold temperature and the like. MCO2 determines molding conditions based on part quality and gate specifications. The database used is common for TMC-MCO and CSE2 and so it interrelates shrinkage with these variables. Once the user analyzes MCO2, the CSE2 program can be accessed to determine the mold dimensions and tolerances for each analyzed dimension.

The CSE2 program utilizes the same database that is used for the TMC-MCO package. Data stored covers all major categories of thermoplastics. Each resin is described by 80 variables related to physical, rheological and thermal properties.

The CSE1 program has its own database that contains shrinkage data for all major categories of thermoplastic materials.

3.4 TMCONCEPT Features

The TMCONCEPT program simulates cavity filling considering molding conditions and also accounts for machine characteristics, shrinkage coefficients for materials and polymer cost. The user is able to incorporate data acquired with experience from previous moldings into new designs. For example, part shrinkage varies with geometry and if shrinkage coefficients are determined for a geometry from experiments, the same can be retained for use in future. This feature of the software is very useful. The molder can select machine characteristics from the database in the program, and also update the database by including in it, characteristics of existing machines.

TMconcept-CSE for shrinkage calculation : CSE1 - CAVITY DIMENSIONS WITH G

CSE1 FILE : DEEX2 - DESCRIPTION : EXAMPLE 2 (10-09-1990)

MATERIAL FILE : PLAST - CODE : M420 - (10-02-1985)
DESCRIPTION : NYLON 6/6 standard

GENERAL VARIABLES :

MATERIAL TEMPERATURE	C	270	-	290
MOLD TEMPERATURE	C	60	-	90
HOLDING PRESSURE	bar	600	-	400
SHRINKAGE [P]	%	1.200	-	1.600
SHRINKAGE [T]	%	1.300	-	1.700
POST-MOLDING DIMENSIONAL CHANGE	%	.5	******	
TOOL MAKING QUALITY ISO 1-17	n.	8		
GENERAL TOLERANCES	micron	100		

IDENTIFICATION DESCRIPTION			PART DIMENSIONS			MOLD DIMENSIONS		
			DIMENSION	TOLERANCE		DIMENSION	TOLERANCE	
n.	deg.	I/M/F	mm	micron		mm	micron	
1	45	I	25.0000	100	-100	25.2357	17	-17
						(25.2190	25.2524)	
2	90	I	25.0000	100	-100	25.2481	17	-17
						(25.2314	25.2649)	
3	0	I	25.0000	100	-100	25.2233	17	-17
						(25.2065	25.2400)	
4	45	M	25.0000	100	-100	25.2275	33	0
						(25.2275	25.2610)	
5	45	F	25.0000	100	-100	25.2456	0	-33
						(25.2121	25.2456)	
6	45	I	10.0000	100	-100	10.0943	12	-12
						(10.0821	10.1065)	

Figure 3.3: Cavity dimensions with given shrinkage

Chapter 4

Previous Experimental Results

4.1 Shrinkage Behavior

In order to study the shrinkage behavior of resins, it is necessary to understand the reason for part shrinkage, which is explained below.

In the period when the melt fills the mold and begins to cool, it tends to shrink, thus changing the part dimensions. To compensate for the shrinkage, pressure is applied to pump more melt into the cavity. This pressure, called the holding pressure or packing pressure, is effective only until the gate, runner or sprue are frozen after which the pressure in the cavity decreases. After the part cools and reaches the required structural stability it is ejected from the mold. The part continues to cool and shrink after ejection from the mold.

Shrinkage measurement is very important in order to mold parts of required dimensions and tolerances. The parameters influencing shrinkage are pressure in the mold cavity, temperature of the melt, viscosity of the melt and the effect of filler materials and reinforcements. At the cavity surface, a frozen skin may be formed, because of very high temperature gradients, that forms an effective insulating layer and so the material underneath the frozen skin cools slowly and continues to flow. This may lead to different shrinkage rates within the mold, and make shrinkage measurement difficult. A change in viscosity of the resin would also vary shrinkage in the part, and shrinkage would increase if the viscosity increases. The molecular orientation of the resin during filling, and fiber orientation in the case of reinforced materials, are other important parameters that influence shrinkage. Reinforced resins exhibit anisotropic mold shrinkage, and shrinkage in the direction of material flow is always less than in the transverse direction[30]. The reason for this characteristic is that the reinforcement fibers tend to align themselves in the direction of the material flow, and when solidification occurs, the fibers inhibit the shrinkage of the material in this direction. The factors influencing shrinkage vary the shrinkage rate within a mold and it is difficult to create a theoretical model that would describe the shrinkage behavior of a mold precisely.

4.2 Previous Experimental Work

Previous experiments on part shrinkage were performed by resin manufacturers and molders on test moldings, that included parts like plates, plaques, or other commonly used shapes with various parameters including part thickness, molding pressure, mold temperature and part geometry. The experimental results described in this chapter are derived from data provided by resin manufacturers' catalogs. The results of the shrinkage tests are plotted as graphs showing the variation of shrinkage coefficient with each of the influencing parameters including gate area, part thickness, direction of flow and mold temperature at different melt temperatures and holding pressures. The results for three resins are described in the following text.

4.2.1 Part Shrinkage of Acetal Copolymer

The following data shows the effect of molding conditions on mold shrinkage in the flow and transverse directions of Acetal Copolymer[30]. The factors influencing mold shrinkage include thermal properties of the resin, temperature range over which the molded part cools, usually room air temperature, part design, particularly wall thickness, mold design and molding conditions.

The following mold shrinkage data was obtained in laboratory studies on standard flexural bar test specimens.

Average mold shrinkage for Acetal Copolymer determined on end gated flex bars (5" Long × 1/2" Wide × 1/8" Thick)

Acetal Copolymer Grade	Shrinkage in Flow Direction inch/inch (mm/mm)	Shrinkage Transverse To Flow inch/inch (mm/mm)
M90	0.023 (0.023)	0.020 (0.020)
M270	0.022 (0.022)	0.020 (0.020)
GC-25A	0.004 (0.004)	0.018 (0.018)

Figure 4.1 and Figure 4.2 show the influence of molding conditions on mold shrinkage, the molding conditions for which are,

Mold Temperature	150 °F
Injection Pressure	14200 psi
Melt Temperature	500 °C

The curves are labelled A through E in order of increasing mold shrinkage. Areas bounded by the highest letter show the range of conditions which will provide the highest mold shrinkage. These two figures and the table may be used as a guide to design a mold for shrinkage.

Standard tensile bar specimens and some design parts are shown in Figure 4.3. Figure 4.4 describes the effects of molding conditions and wall thicknesses on

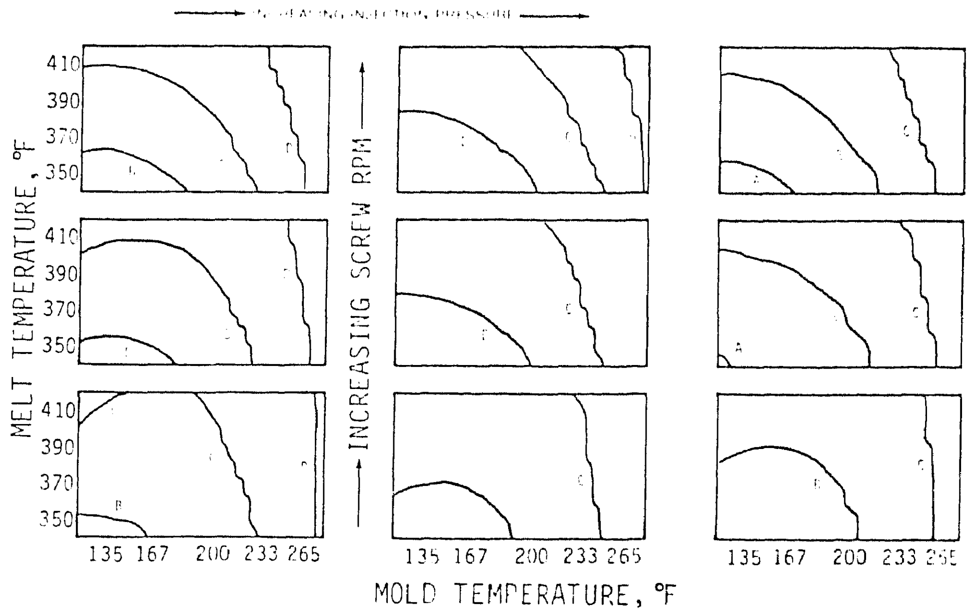
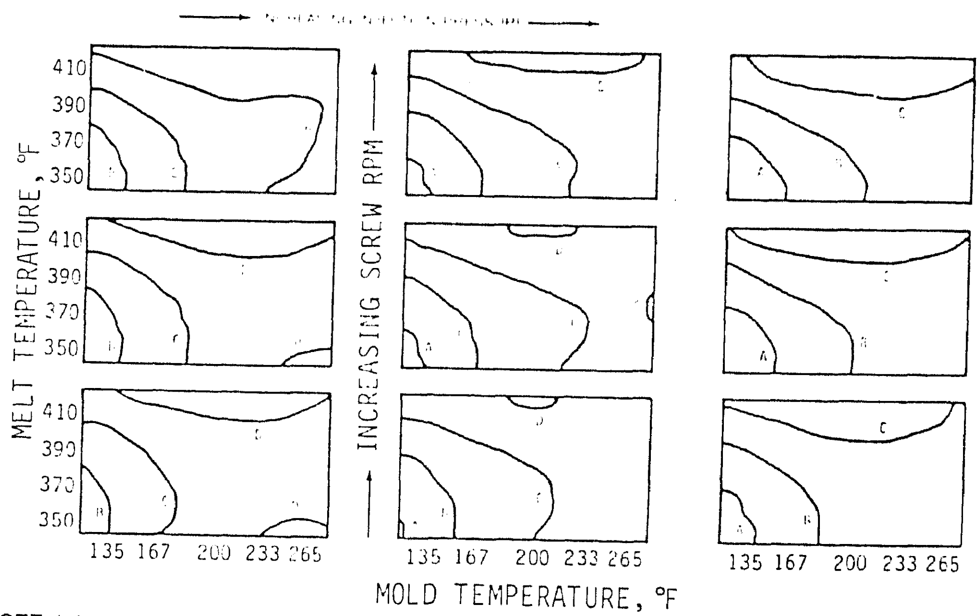


Figure 4.1: Influence of molding conditions on mold shrinkage of Acetal Copolymer in direction of flow. Ref: Manufacturer's brochure, Celanese Engineering Resins, a division of Celanese Corporation.



NOTE: Injection pressures ranged from 5,000 to 15,000 psi, while screw rotational speeds ranged from 40 to 120 rpm.

Figure 4.2: Influence of molding conditions on mold shrinkage of Acetal Copolymer transverse to flow. Ref: Manufacturer's brochure, Celanese Engineering Resins, a division of Celanese Corporation.

mold shrinkage.

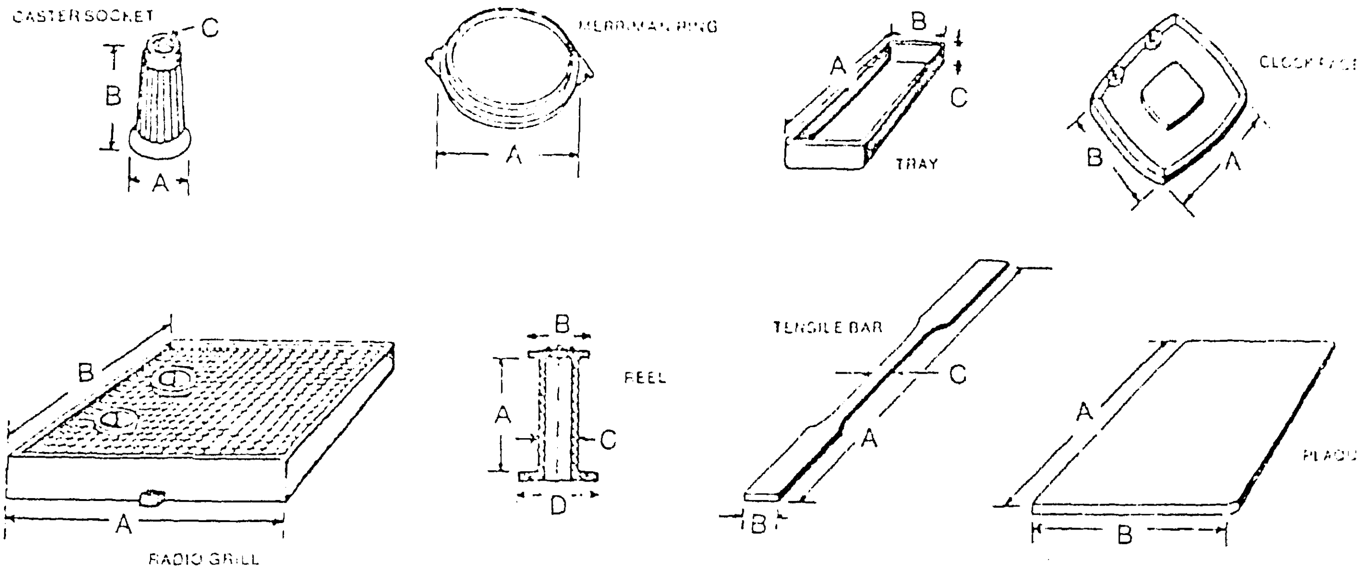
Annealing parts of Acetal Copolymer in a post molding operation will cause shrinkage and an additional allowance must be made for the mold cavities and cores, typical values for which are also supplied by the manufacturer[30].

4.2.2 Part Shrinkage of Acetal Homopolymer

The following figures describe the shrinkage variation for Acetal Homopolymer from data supplied by the manufacturer, DU PONT[31].

The mold shrinkage of Acetal Homopolymer acetal resins is dependent on such factors as mold temperature, injection pressure, screw forward time, melt temperature, gate size and part thickness. The manufacturer has developed a nomograph to show the relation of mold shrinkage to the combined effect of part thickness and gate area. The nomograph is shown in Figure 4.5. There are two sets of values of mold shrinkage marked typical and optimum. Both sets of values are based on a mold temperature of 93°C (200°F), injection pressure of 112 MPa (16,000 psi), and a melt temperature of 210°C (410°F). For the optimum values, it is assumed that the the gate is designed with a minimum thickness equal to one-half of the wall thickness. It is also assumed that screw forward time is at least equal to the time required for the gate to freeze. When molding with a screw forward time less than the time required for gate to freeze, the shrinkage values are closer to those shown as typical values. Figure 4.6 shows post- molding shrinkage values for Acetal Homopolymer.

Mold Temperature	93 °C
Injection Pressure	112 MPa
Melt Temperature	210 °C



	Molding Conditions		Dimensions	Shrinkage	Gate
Part Name	Material Temp., °F	Mold Temp., °F	Inches	In./In.	
Caster Socket	380	200	A 13/16 B 1-7/8 C 0.450 D (hole thru)	0.020 0.037 0.022	one at lower edge
Merriman Ring	420	[illegible]	A [illegible]	0.025	one - inside edge
Radio Grill	410	210	A 5 B 5-3/8 (0.062 section)	0.019 0.020	one at side lug
Reel	420	220	A 10 B 5-1/16 C 3 (D) D 6-5/16 D (0.0250 section)	0.026 0.028 0.028 0.030	4-1/8" Radius half round, on top
Tray	400	220	A 12 B 7 C 2 (0.070 section)	0.020 0.023 0.022	3 on bottom center line
Clock Face	390	230	A 6 B 5¼ (0.100 section)	0.027 0.029	one at lower edge opposite holes
Tensile Bar	400	180	A 8½ B ¾ C ½ (0.125 section)	0.026 0.020 0.019	one at corner
Plaque	400	200	A 5 B 3 (0.125 section)	0.019 0.017	one at corner

Figure 4.3: Typical part shrinkage for Acetal Copolymer. Ref: Manufacturer's brochure, Celanese Engineering Resins, a division of Celanese Corporation.

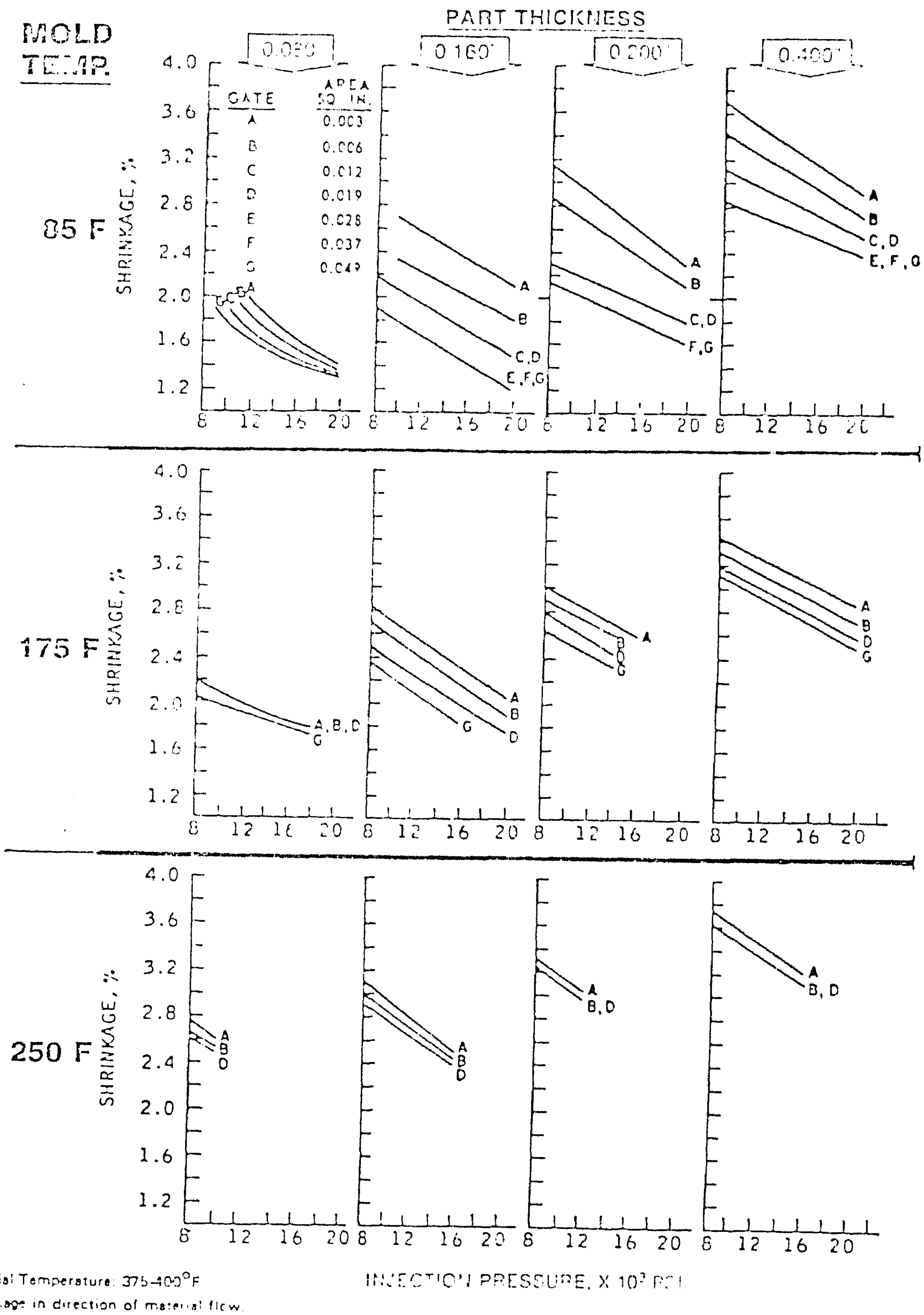


Figure 4.4: Effect of molding conditions and wall thickness on mold shrinkage of Acetal Copolymer. Ref: Manufacturer's brochure, Celanese Engineering Resins, a division of Celanese Corporation.

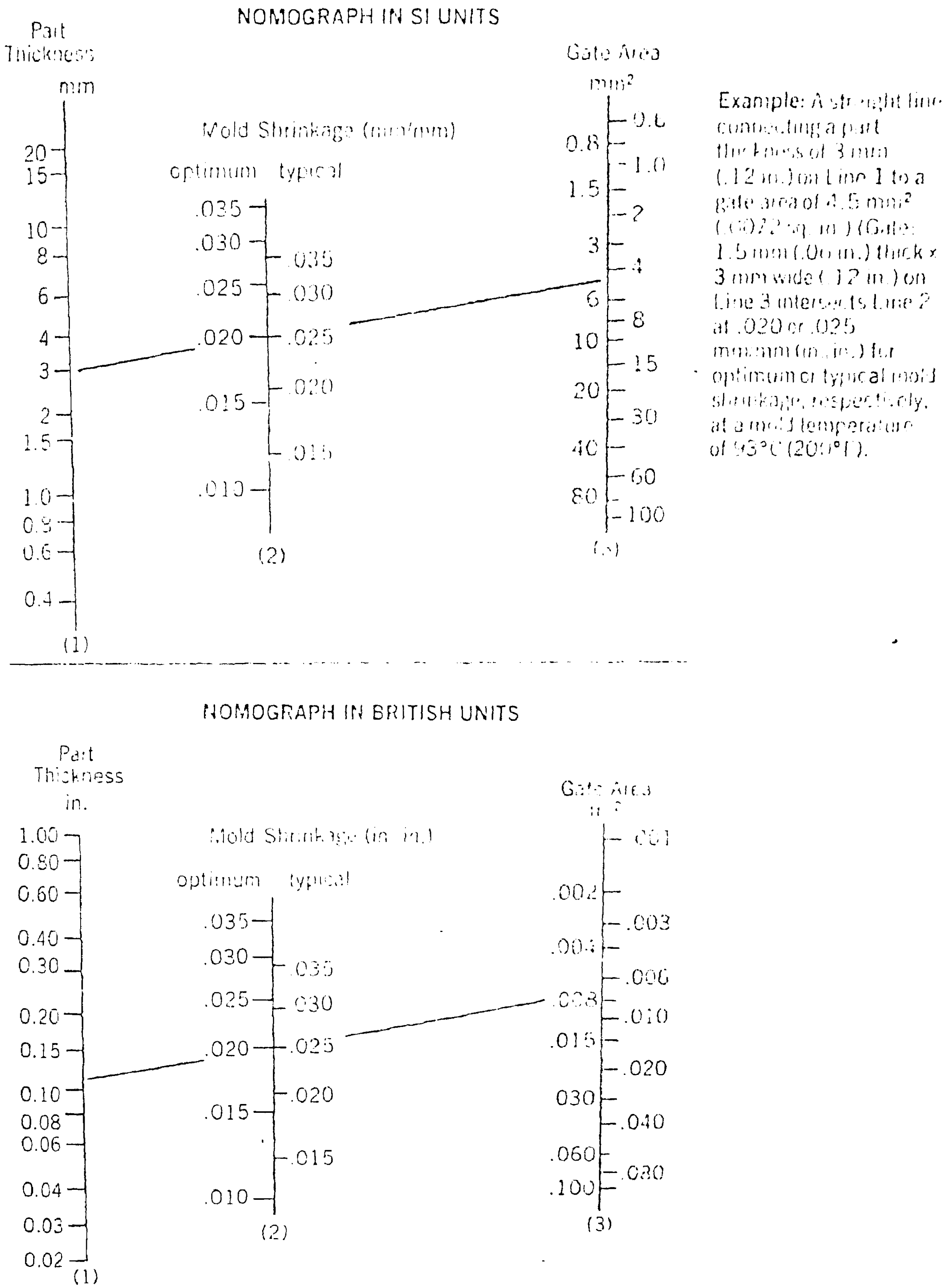


Figure 4.5: Nomograph to determine mold shrinkage for varying molding conditions for Acetal Homopolymer. Ref: Manufacturer's brochure, Delrin Acetal Resins, DUPONT.

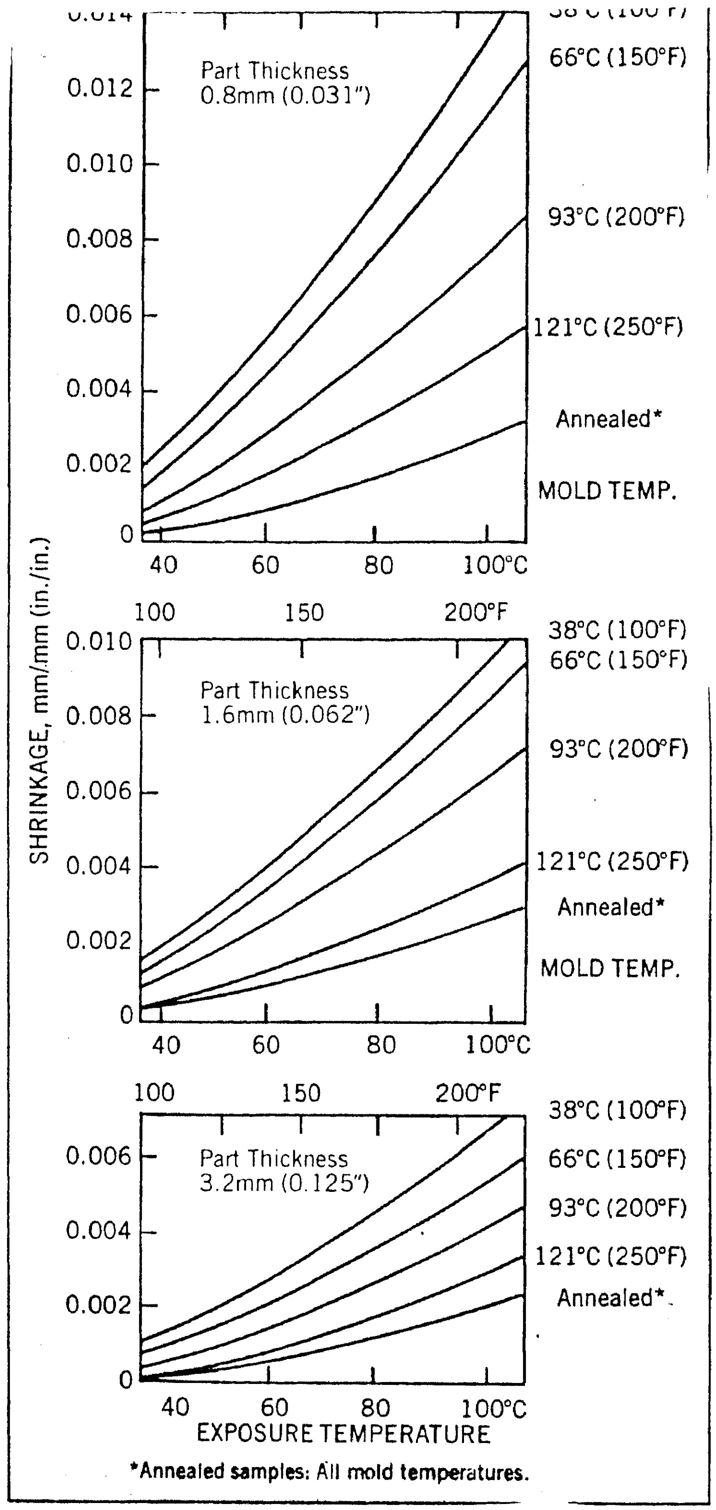


Figure 4.6: Post molding shrinkage of Acetal Homopolymer. Ref: Manufacturer's brochure, Delrin Acetal Resins, DUPONT.

4.2.3 Part Shrinkage of Nylon 66

The following figures describe shrinkage variation for Nylon 66 resins from data supplied by the manufacturer, DUPONT[32]. The mold shrinkage for a range of grades of Nylon 66 specified in the manufacturers' brochure can be approximated by two nomographs shown in Figure 4.7 and Figure 4.8. The nomograph is divided into two sections, section A depends on the mold design and section B depends on the molding conditions and type of nylon. The mold shrinkage for a resin is determined by adding the value A obtained from the mold variables and and the value B obtained from the processing variables. For example, to estimate the mold shrinkage of Zytel 131 NC-10 in a 3" × 6" × 0.125" plaque mold with a rectangular gate 0.09" thick and 0.125" wide. Inserting the mold dimensions into Figure 4.7, the value of A is calculated as 20.5 milsin. Also, inserting into Figure 4.8, melt temperature equal to 550°F, mold temperature of 150°F, and injection pressure of 15,000 psi, until line B1 is reached. Proceed horizontally from line B1 to line B4 for Zytel 131 L NC-10 and get the values of B4, which are 14 milsin in the direction of flow and 9 mils/in transverse to flow.For half-round gates, the effective gate thickness is 80 % of the radius and the effective gate width is equivalent to the diameter. The mold shrinkage of other Nylon 66 resins not shown in Figure 4.7 and Figure 4.8, are given in Figure 4.9.

Mold shrinkage of other Nylon 66 resins

(not covered in Figure 4.7 and Figure 4.8. Ref: Manufacturer's brochure, Zytel Nylon Resins, DUPONT)

Resin	Shrinkage(mils/inch)[1] 1/16 in thick (1.59 mm)	Shrinkage(mils/inch)[1] 1/8 in thick (3.17 mm)
ZYTEL 151 L NC-10	7-13	10-17
ZYTEL 158 L NC-10	7-13	10-17

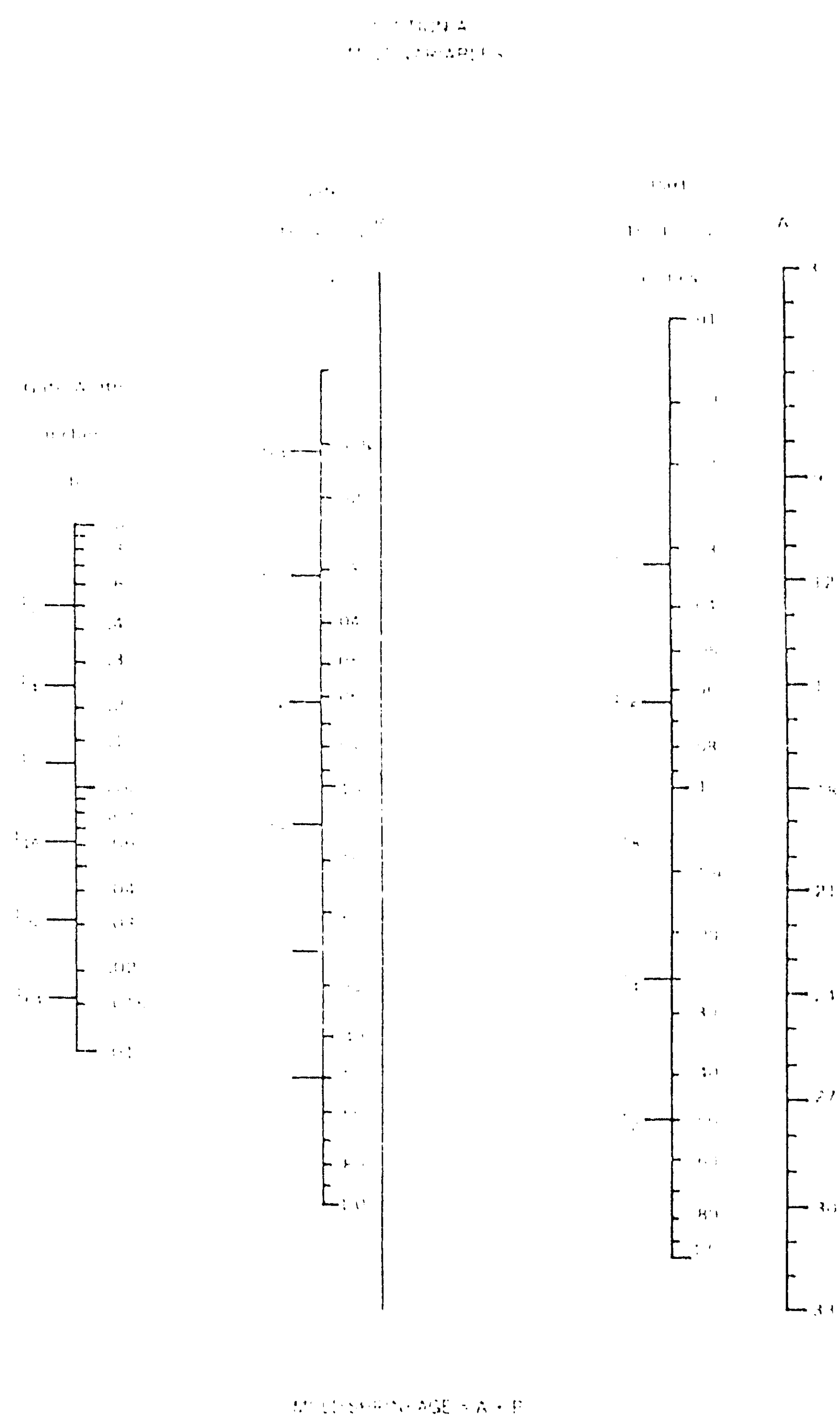
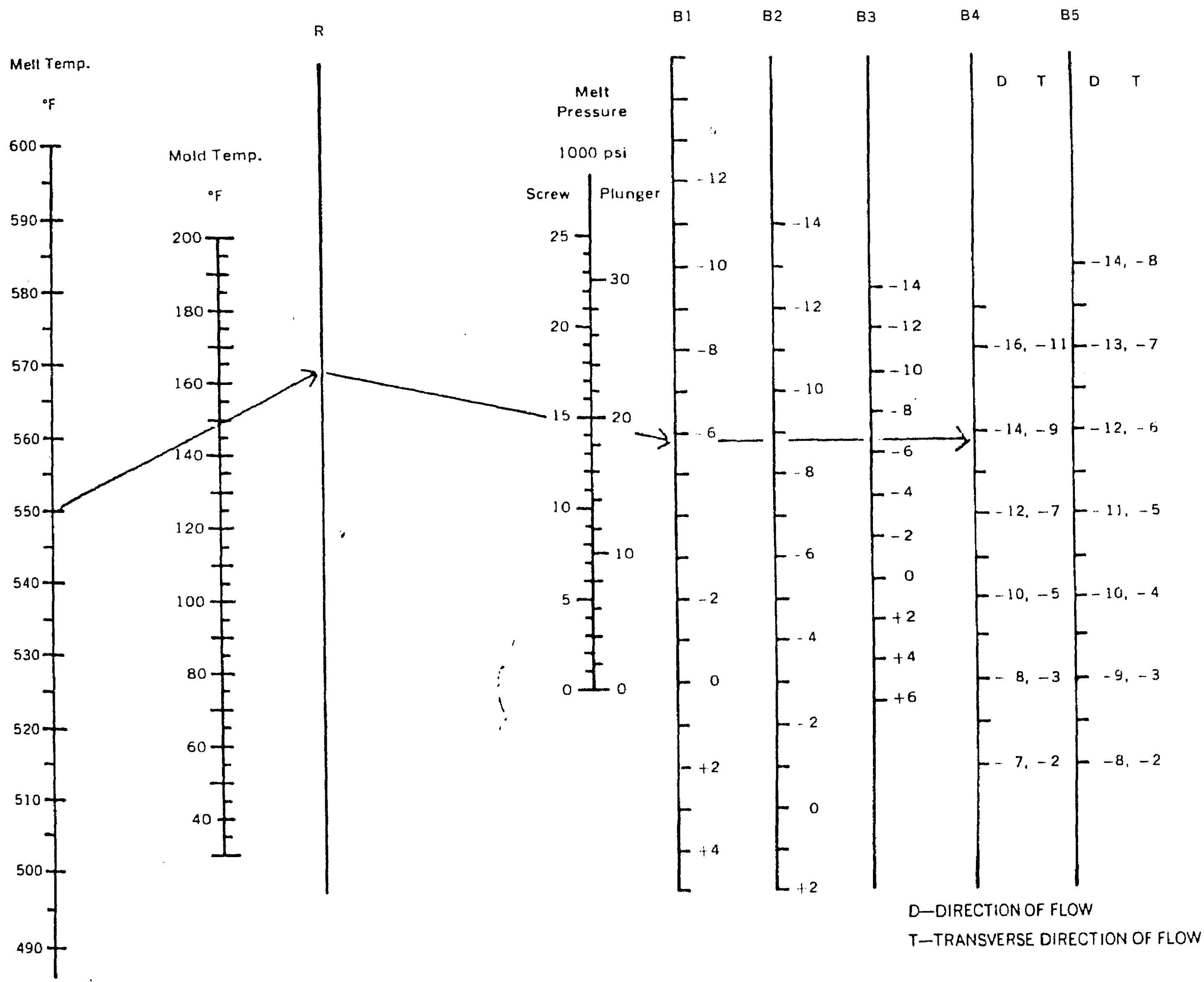


Figure 4.7: Variation of mold shrinkage for Nylon 66 -Part A. Ref: Manufacturer's brochure, Zytel Nylon Resins, DUPONT



KEY
B1="ZYTEL" 101 NC-10, "ZYTEL" 101 L NC-10, "ZYTEL" 103 HS-L NC-10
B2="ZYTEL" 105 BK-10A
B3="ZYTEL" 408 NC-10
B4="ZYTEL" 131 L NC-10
B5="ZYTEL" 109 L NC-10

Figure 4.8: Variation of mold shrinkage for Nylon 66 -Part B. Ref: Manufacturer's brochure, Zytel Nylon Resins, DUPONT

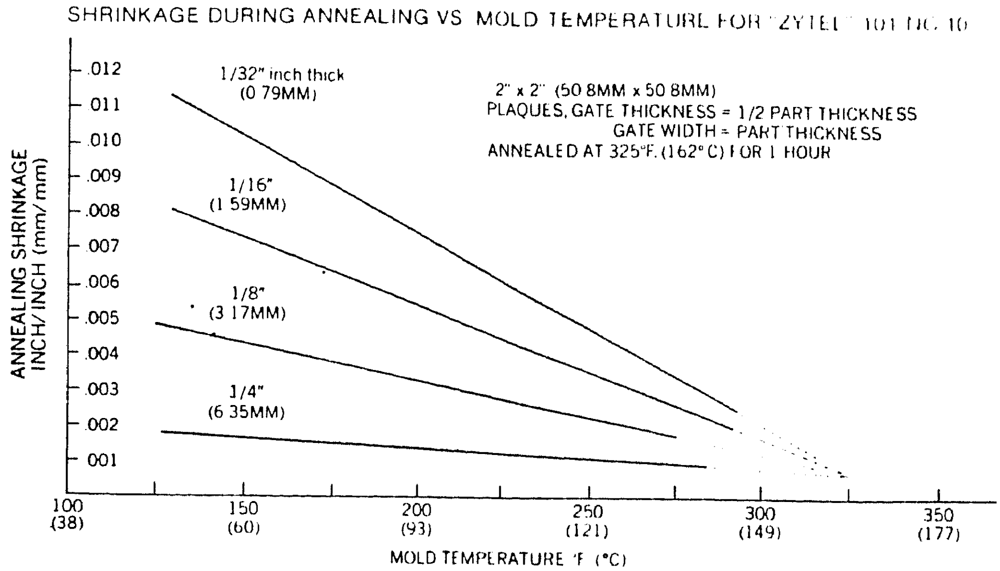


Figure 4.9: Shrinkage during annealing vs. mold temperature for Nylon 66. Ref: Manufacturer's brochure, Zytel Nylon Resins, DUPONT.

Legend: 1. Data based on 3" × 5" (75 mm × 125 mm) × thickness plaques.

The annealing shrinkage of plaques of Nylon 66 (2" × 2" (50 mm × 50 mm) × various thicknesses) versus mold temperature is given in Figure 4.9. Figure 4.10 shows the combined mold shrinkage and annealing shrinkage as a function of mold temperature for the same plaque of ZYTEL 101.

4.3 Need for Shrinkage Experiments

Material suppliers provide average shrinkage coefficients for most of resins. The values of shrinkage coefficients are obtained by experimenting on test molds with various part thicknesses and varying molding conditions. The mold geometry may be as simple as a rectangular plate or shrinkage could be measured for common shapes and sizes. For example, the test part could be a bar, 5 × 1/2 × 1/8 inches, or a plaque, 3 × 13/4 × 1/8 inches, or an ASTM tensile bar, 1/8 inch thick. Mold

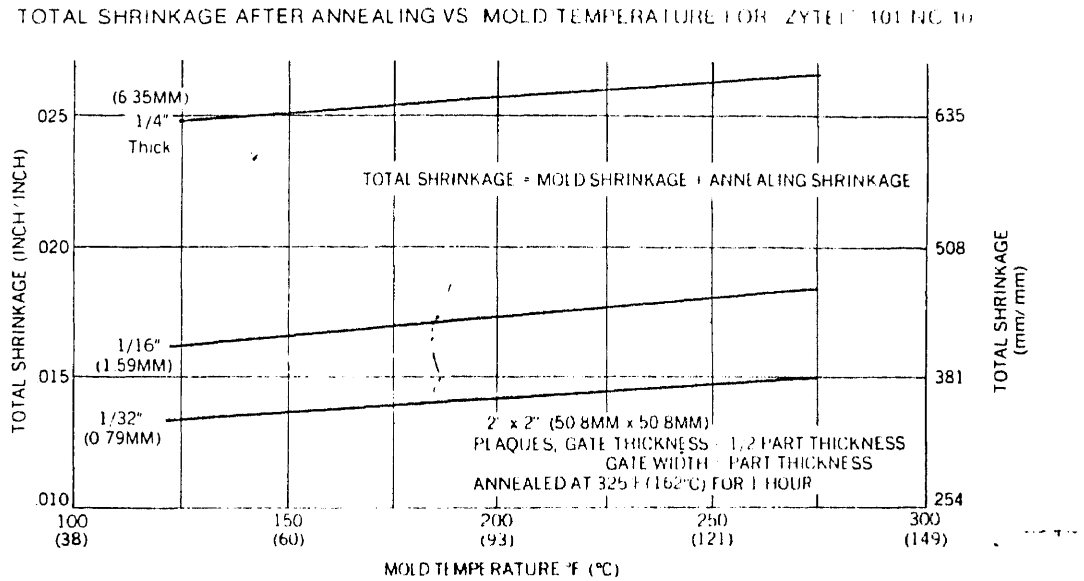


Figure 4.10: Total shrinkage after annealing vs. mold temperature for Nylon 66. Ref: Manufacturer's brochure, Zytel Nylon Resins, DUPONT.

dimensions and part dimensions are measured with varying molding conditions for different part thicknesses. The shrinkage coefficients measured for these tests may not hold good for practical applications. The mold design considering these shrinkage values would produce parts that might not meet tolerance requirements. Hence the mold designer would rely on a method wherein the mold cavity would be undercut and a test run made. The cavity is made larger according to measurements on part dimensions. This delays the production start-up and increases the cost. A CAD simulation of part shrinkage that would yield actual shrinkage values will help the mold designer to achieve required tolevances by eliminating the trial run. A simulation model of shrinkage must account for the interrelated factors such as part geometry, mold design and molding conditions that affect shrinkage variation.

Material shrinkage data parallel and transverse to flow are different and should be considered individually in any simulation model. During the period when the melt cools, the inner material cools at a slower rate than the outer surface, because of which, there is an increase in melt viscosity in the outer part of the melt and thus increased shrinkage. Another difference in shrinkage data parallel, and transverse, to the flow is because of the decrease in pressure in the direction of flow that causes a decrease in melt viscosity and an increase in the shrinkage in the direction of flow. The other factors that influence shrinkage are crystallinity and molecular weight. The shrinkage rate for amorphous polymers is much less than for crystalline materials. For crystalline resins such as polypropylene, polyethylene and polyacetal the specific volume decreases significantly at the freezing or melting temperature whereas for amorphous polymerw there is a gradual change in specific volume with temperature. In the melt, the polymer chains are in a disordered mass. When the polymer solidifies, the chains form a more orderly and dense crystalline structure, thus increasing the density and the shrinkage. Thus, shrinkage for amorphous polymers is much less than for crystalline materials. Molecular weight also influences shrinkage. A higher molecular weight causes an increase in melt viscosity and also increases the pressure gradient during mold filling, resulting in lower pressure in the cavity, and may lead to increased shrinkage. Reinforcements generally cause a reduction in shrinkage, but they may diminish the difference between longitudinal and transverse shrinkage.

Part geometry has a major influence on shrinkage. Thicker parts reduce the cooling rate thus increasing shrinkage, particularly in unreinforged crystalline materials. Restrictions along the flow path reduce the available pressure in the cavity as well as the time over which it is applied, thus increasing shrinkage. This happens when long, restrictive runners are employed.

Mold variables, such as runner dimensions and gate sizes, influence the pressure applied to the mold cavity and thus affect the shrinkage. The mold temperature affects the rate of cooling of the material and thus causes shrinkage variation.

Molding conditions, such as holding pressure, melt temperature, injection rate and hold time have been found to influence shrinkage. Higher melt temperature and higher mold temperature cause an increase in shrinkage. The mold temperature influences shrinkage more than the melt temperature since it can be varied over a wider range. The influence of the injection speed on shrinkage is complex and difficult to predict. At low speeds, the frozen skin is thicker and this would increase shrinkage. Other factors influencing shrinkage are orientation, changing flow rate and shear rate.

Post-molding changes due to moisture absorption must also be accounted for in evaluating a shrinkage model. The shrinkage evaluation would suggest the tolerance limits that could be achieved in the molded part and the degree of difficulty encountered in attaining them. Process variability such as shot-to-shot fluctuation of melt pressure and temperature that is inherent to the molding machine are important in shrinkage analysis. The shrinkage analysis should be coordinated with a molding analysis that accounts for all influencing factors.

The following table describes the parameters that influence mold shrinkage.

Parameter	Shrinakge
In the direction of flow	Increases
Transverse to flow	Decreases
Increase in melt viscosity	Decreases
Increase in pressure	Decreases
Reinforcements	Decreases
Increase in part thickness	Increases
Higher melt temperature	Increases
Higher mold temperature	Increases

Chapter 5

Results

5.1 Part Shrinkage of Acetal Copolymer

For both flow and transverse directions, mold shrinkage decreases with increasing injection pressure, increasing injection speed, decreasing mold temperature and melt temperatures in the lower molding range of 340 to 360°F (171 to 182°C). Conversely mold shrinkage increases with decreasing injection pressure, decreasing injection speed, increasing mold temperature and melt temperature in the range of 360 to 410°F (182 to 210°C). Typical molding conditions suggested for providing minimum and maximum mold shrinkage are delineated below:

	Minimum Mold Shrinkage	Maximum Mold Shrinkage
Melt Temperature, $^{o}F(^{o}C)$	340-360 (171-182)	360- 410 (182-210)
Mold Temperature, $^{o}F(^{o}C)$	110-230 (43-110)	250 (121)
Injection Pressure, psi	15,000-20,000	5,000
Injection Speed	Maximum	Minimum

Screw rotational speed has little effect on mold shrinkage of unreinforced Acetal Copolymer grades.

The following table summarizes the effect of molding conditions on mold shrinkage for unreinforced Acetal Copolymer.

Mold Shrinkage	Injection Pressure	Melt Temperature	Mold Temperature	Screw Speed	Injection Speed
To Decrease	Increase	Decrease	Decrease	–	Increase
To Increase	Decrease	Increase	Increase	–	Decrease

Legend : – No Significant Effect.

Because of the several influencing factors, it is difficult to predict mold shrinkage precisely particularly in parts of complex geometry, because of uneven shrinkage rates. By simulating the cavity filling process, this task could be made easier by predicting the shrinkage, using stored data from shrinkage experiments.

5.2 Part Shrinkage of Acetal Homopolymer

The mold shrinkage of Acetal Homopolymer resins is dependent on such factors as mold temperature, injection pressure, screw forward time, melt temperature, gate size and part thickness.

For parts of uniform wall thickness, mold shrinkage tends to be uniform throughout. For parts having variable thickness, shrinkage will tend to be nearly uniform if it is gated into the heaviest section, the gate is properly sized, and screw forward time equals or exceeds gate freeze time otherwise, shrinkage will tend to be greater in the thick sections.

In actual moldings shrinkage values may vary from the estimated values because of such as factors as insufficient machine capacity, insufficient clamp capacity, different melt temperatures, screw forward time shorter than gate seal time, too rapid freezing of a very thin gate, operating with mold temperature other than 93°C (200°F), injection pressure too low, poor gate location for adequate filling of mold.

5.3 Part Shrinkage of Nylon 66

Mold shrinkage depends on the type of nylon being processed, the molding conditions and the mold design. The as-molded crystallinity of parts molded in Nylon 66 depends on the mold temperature, part thickness and the type of nylon being processed. Appreciable post-molding crystallization is observed in thin sections molded in cold molds that results in additional part shrinkage whereas the crystallinity of thick section parts molded in hot molds remains fairly constant. The annealing process increases the rate of post- molding shrinkage. For any part thickness, the annealing shrinkage decreases with increasing mold temperature and the annealing shrinkage increases as the part thickness decreases at constant mold temperature. The total shrinkage is only slightly affected by mold temperature.

Chapter 6

Conclusions

Evaluation of part shrinkages is very important for mold parts to ensure accuracy. Part shrinkage behavior is influenced by molding conditions and part thicknesses, and prediction of shrinkage is difficult. Shrinkage behavior prediction can be improved with CAD simulations. Part shrinkage coefficients evaluated by resin suppliers are average values observed in experiments on standard shapes and sizes at specified molding conditions. In actual moldings, part shapes and sizes may be different than those used by the resin supplier, and it may be necessary to perform experiments to predict part shrinkage using actual molding conditions and actual part geometries. CAD simulations of the cavity filling process can be used to predict part shrinkage. This is performed by storing experimental data from part shrinkage experiments and then using the stored data to interpolate, or extrapolate, during actual applications.

The currently used methods in CAD mold design have one major drawback that mold designers experience. The variation in shrinkage coefficients for different resins cannot be compensated for and one cannot predict whether a specific part can be manufactured without warpage. Most CAD simulations cannot accurately predict the variation in shrinkage rates across all dimensions of a specific part. The shrinkage rates vary with material type and part geometry from 1% to 10%[10]. The method used at present by most mold designers to extrapolate an average shrinkage coefficient given by the resin supplier into accurate shrinkage compensation values for all critical dimensions of a specific part is to allow for the effect of changes in wall thickness and other dimensional variations on shrinkages rates. The general practice adopted by mold makers is to cut the mold cavity undersize and then enlarge it gradually by measuring a series of trial parts to account for actual part shrinkage rates.

The shrinkages values that are evaluated from such experiments are used to construct the mold undersize, so that part tolerances are met. The shrinkage coefficient is expressed as a percentage of part size, with molding conditions specified as used during the experiments. The variation of part shrinkage with respect to molding conditions are plotted praphically, and these graphs are used to correlate actual molding conditions with actual shrinkage values. The molding conditions can thus be varied to obtain required part tolerances.

Chapter 7

Future Work

7.1 Experiments using TMCONCEPT

The shrinkage analysis is conducted on a resin to determine the gate freeze-off time, minimum ejection time, optimal ejection time and part shrinkage parallel, and transverse, to flow. The experimental setup suggested by TMCONCEPT includes, a mold with adjustable part thickness and a suitable molding machine, that are described in the following text.

The test mold should have a rectangular cavity with side dimensions greater than 50 mm whose thickness can be changed. A rectangular gate should be located in the middle of one side of the cavity, with the facility to change gate dimensions independent of part thickness. The gate width should be greater than or equal to the gate thickness with a 0.5 mm constant gate length with smoothing radii. The runner system should have short runners with a diameter greater than or equal to 1.4 times part thickness, which meet the gate at an angle of 45 degrees. There should be an an effective ejection system helped by adequate taper on the sides of the part side. Eight measuring surfaces without taper should be provided on the part to be used in precise shrinkage measurements. These measuring surfaces should be about 5 mm long, have a width slightly less than the part thickness (to avoid the influence of the edges during part measurements) and should be located about 5 mm from the four corners of the rectangular part. There should be an efficient cooling system, which preferably is machined directly into the cavity insert.

The molding machine that is to be used for the experiment should have, an excellent shot to shot reproducibility of processing variables ample plasticating capacity and an ability to provide thoroughly homogeneous melt for the entire volume required for one shot.

The tests are to be carried out under the following conditions:

- constant melt temperature
- at least 3 mold temperatures
- at least 3 holding pressures
- at least 3 part thicknesses
- at least 4 gate to part thickness ratios. A gate thickness equal to the part thickness must be included in this evaluation. Other gate to part thickness ratios ranging from 3/4 to 1/4 are suggested. Testing the full range of gate thicknesses is especially important for the most typical part thickness in which the particular resin is used.

Two types of tests are to be performed, one in which gate thickness is equal to the part thickness and the other in which gate thickness is less than part thickness. The experimental data is recorded in the following tables.

Tests with gate thickness = part thickness.

PART DIMENSIONS (measuring precision > 1/5000 of dimension)

Thickness:	[shrink.P1]
Width near gate:	[shrink.T]
Width opposite gate:	[shrink.P2]
Length:	

GATE DIMENSIONS

Thickness:	Width:	Length: 0.5 mm

MELT TEMPERATURE INJECTION TIME (part only) FLOW RATE MOLD OPENING AND CLOSING TIME MOLD TEMPERATURE (evaluate at least 3 temperatures)[1]	

	UNITS	TEST 1	TEST 2	TEST 3
HOLDING PRESSURE				
HOLDING PRESSURE TIME[2]				
PLASTICATING TIME				
TOTAL CYCLE[3]				
PART WEIGHT[4]				
SHRINKAGE P1[5]	%			
STANDARD DEVIATION				
SHRINKAGE P2	%			
STANDARD DEVIATION				
SHRINKAGE P3	%			
STANDARD DEVIATION				

Legend:

(1) Evaluate at least 3 holding pressures (e.g. 200, 800, 1400 bar) at each of 3 mold temperatures.

(2) Minimum time to attain maximum part weight.

(3) To achieve best dimensional results.

(4) Parts to be conditioned in dry atmosphere at 23°C for at least 24 hours prior

to measuring. Use care to avoid erroneous readings through contact with the part edges.

$$SHRINKAGE(\%) = \frac{(MOLD\ DIMENSION - PART\ DIMENSION)}{MOLD\ DIMENSION} * 100 \tag{7.1}$$

Tests with gate thickness ¡ the part thickness.

PART DIMENSIONS (measuring precision ¿ 1/5000 of dimension)

Thickness:	[shrink.P1]
Width near gate:	[shrink.T]
Width opposite gate:	[shrink.P2]
Length:	

GATE DIMENSIONS

Thickness:	Width:	Length: 0.5 mm

PART THICKNESS	
GATE THICKNESS/PART THICKNESS RATIO	
MELT TEMPERATURE	
INJECTION TIME (part only)	
FLOW RATE	
MOLD OPENING AND CLOSING TIME	
MOLD TEMPERATURE[6]	
HOLDING PRESSURE[6]	

	UNITS	TEST 1	TEST 2	TEST 3
HOLDING PRESSURE TIME				
PLASTICATING TIME				
TOTAL CYCLE A[7]				
PART WEIGHT				
SHRINKAGE P1	%			
STANDARD DEVIATION				
SHRINKAGE P2	%			
STANDARD DEVIATION				
SHRINKAGE P3	%			
STANDARD DEVIATION				
TOTAL CYCLE B[8]				
PART WEIGHT				
SHRINKAGE P1	%			
STANDARD DEVIATION				
SHRINKAGE P2	%			
STANDARD DEVIATION				
SHRINKAGE P3	%			
STANDARD DEVIATION				

Legend:

(6) Typical values.

(7) Minimum cycle to eject without deformation.

(8) Cycles must be identical to those of the preceding test (Gate Thickness = Part Thickness).

7.2 Integration Of Data Into TMCONCEPT

The data obtained from the experiments should be retained for future use. The TMC-CSE program has this facility and a molder can perform shrinkage experiments with actual parts and molding conditions, and store the data in the CSE database. The Update routine has to be used to add new data. The CSE program can calculate dimensions of the mold corrected for shrinkage, thus saving much time in shrinkage computation. Such data can provide better accuracy in predicting shrinkage for mold dimensions. Consequently, tolerances on mold are specified depending on tolerances specified on part. This feature will indicate whether specified part tolerances could be met with no allowance for shrinkage, thus saving time and cost. The molder can also change part tolerances to eliminate shrinkage allowance, if it is feasible. Thus, the shrinkage evaluation routine is integrated with design routines to effectively predict mold dimensions and tolerances directly, and also predict cost savings whenever feasible. Figure 5.1 lists materials with codes, in the CSE database.

7.3 Proposed Experimental Plan

Part shrinkage as measured by resin suppliers may not hold good in actual moldings. The suppliers' data is based upon test specimens that may include bars, plaques, or other shapes. Geometry of actual moldings may be intricate and may produce part shrinkage varying from predicted coefficients. Hence, it is desirable to perform shrinkage tests on parts, with different geometries, different resins and with varying molding conditions, to generate a database that will predict part shrinkage with a better accuracy.

The experiments could be performed on actual part geometries, using actual materials and at actual molding conditions. The data for the experimental plan may also be gathered from existing products from different manufacturers. A computer model could be developed to interpolate or extrapolate the stored data for actual moldings. A database could be maintained to show the shrinkage variation for frequently used mold shapes and sizes with various molding conditions. This would make part shrinkage prediction more accurate. This database could be coupled with a CAD/CAM system so that mold dimensions could be corrected for shrinkage and

TMconcept-MCO for molding optimization : UPDATE MATERIAL FILE (R.4.6)

MATERIAL FILE : PLAST

CODE	ABBREVIATION	DESCRIPTION
M100	ABS gp	ABS general purpose
M110	ABS mhi	ABS medium high impact
M115	ABS vhi	ABS very high impact
M120	ABS mhr	ABS medium heat resistant
M125	ABS hhr	ABS high heat resistant
M130	ABS 15-20% gr	ABS - 15-20% glass reinforced
M140	ABS fr	ABS flame retardant
M200	POMh mv	ACETAL HOMOPOLYMER medium viscosity
M202	POMh hv	ACETAL HOMOPOLYMER high viscosity
M204	POMh lv	ACETAL HOMOPOLYMER low viscosity
M210	POMh 20% gf	ACETAL HOMOPOLYMER - 20% glass fille
M250	POMc mv	ACETAL COPOLYMER medium viscosity
M252	POMc hv	ACETAL COPOLYMER high viscosity
M254	POMc lv	ACETAL COPOLYMER low viscosity
M260	POMc 25% gc	ACETAL COPOLYMER - 25% glass coupled
M300	PMMA mv	ACRYLIC medium viscosity
M302	PMMA hv	ACRYLIC high viscosity
M304	PMMA lv	ACRYLIC low viscosity
M306	PMMA ir	ACRYLIC impact resistant
M400	PA 6	NYLON 6
M409	PA 6 35% gr	NYLON 6 - 35% glass reinforced
M410	PA 6 30% gr	NYLON 6 - 30% glass reinforced
M411	PA 6 25% gr	NYLON 6 - 25% glass reinforced
M412	PA 6 20% gr	NYLON 6 - 20% glass reinforced
M420	PA 6/6 std	NYLON 6/6 standard
M425	PA 6/6 n	NYLON 6/6 nucleated
M428	PA 6/6 40% gr	NYLON 6/6 - 40% glass reinforced
M429	PA 6/6 35% gr	NYLON 6/6 - 35% glass reinforced
M430	PA 6/6 30% gr	NYLON 6/6 - 30% glass reinforced
M432	PA 6/6 25% gr	NYLON 6/6 - 25% glass reinforced
M434	PA 6/6 20% gr	NYLON 6/6 - 20% glass reinforced
M435	PA 6/6 10-15% im	NYLON 6/6 - 10-15% glass reinf. impa
M440	PA 6/6 mr	NYLON 6/6 mineral reinforced
M450	PA 6/12	NYLON 6/12
M460	PA 11	NYLON 11 'RILSAN'
M470	PA 12	NYLON 12
M480	PA 12 30% gr	NYLON 12 - 30% glass reinforced
M500	PPO mod	'NORYL' 731
M503	PPO mod fr	'NORYL' SE0
M510	PPO mod 30% gr	'NORYL' GNF3 - 30% glass reinforced

Figure 7.1: List of materials in CSE database

machined directly.

Research in this area could use a software package to store the test data and extrapolate shrinkage coefficients for different part dimensions. Moldflow Pty., has developed a software package that predicts actual shrinkage rates and not just average coefficients[10]. This package could increase the accuracy of mold designs, reduce mold rework and virtually eliminate post-molding warpage of parts. The software is now being tested by a selected group of resin suppliers and molders.

Such experimentation will require molds with geometries that are commonly used in actual products. This will need much investment to construct molds of required shapes and sizes. Many molders and suppliers could, instead, share their experiences and store the past history in a database.

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